JSC RESEARCH & TECHNOLOGY 1991 ANNUAL REPORT

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Annual Report 1991

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Prepared by
New Initiatives Office
Lyndon B. Johnson Space Center
Houston, Texas

About the cover...

The illustration depicts NASA exploration aimed at acquiring knowledge about the universe, matter, and the processes that underlie the evolution/development of life on the planet Earth. The envisioned program infrastructure includes shuttles, Space Station Freedom, lunar and Mars outposts, observatories, and probes. The spinoffs of NASA's research, technology, and development that benefit our Nation are highlighted. The illustration was conceptualized by Dr. Kumar Krishen and created by artist Jennifer Hees.

Foreword

During the past year, the Johnson Space Center (JSC) has reviewed its strengths and developed the Center Strategic Plan, reflecting our expertise and willingness to lead the Agency's space exploration program. Our role in fulfilling successfully the commitments to the Shuttle and Space Station Programs will continue in the years to come. The experience and knowledge we have gained will be utilized in developing the infrastructure and distributed systems needed for the space exploration program. We have concluded that future missions in support of space exploration will require systems that can operate autonomously and with a high degree of reliability for long periods of time. These systems must be extremely cost-effective and should require minimal logistics support. The JSC research and development efforts will continue, along with other Centers, to assure that these requirements can be met and that technologies will be available when needed. The JSC will also foster the Nation's technological competitiveness by facilitating early applications of the Agency's technology development to space exploration as well as to the commercial sector. This annual report is to acquaint you with some of the investigations currently being pursued at JSC.

Your comments would be appreciated and should be directed to Dr. Kumar Krishen, Code IA4, NASA Johnson Space Center, Houston, TX 77058.

William J. Huffstetler, Jr.
Manager, New Initiatives Office

Introduction

The Johnson Space Center (JSC) Research and Technology Annual Report is published to highlight the Center's activities and accomplishments during the preceding year. The context in which JSC research and technology (R&T) efforts should be viewed is provided through the words of President Bush on January 24, 1992, when he addressed more than 100 school children and their advisors in the presence of Vice President Quayle, NASA Administrator Truly, and several astronauts. He said, "America's destiny must include manned exploration of space." He went on to add, "We have challenged America to go back to the Moon to stay and then on to Mars." These and other visions for the Nation's space program have been stated by the President on several occasions in the past 3 years. "The JSC Strategy 1992," a plan issued recently, capitalizes on the main theme of the Nation's space program, "Pioneering Space Exploration." The goal of JSC is to lead the expansion of human activity in the exploration and utilization of space. The Center has the experience and the expertise to lead this Nation's space exploration endeavors for space exploration initiative and Space Station (Shuttle-tended phase) Program execution. Further, JSC is the center for excellence in the technology and development related to manned space operations; infrastructure and distributed systems for extraterrestrial outposts and bases; piloted spacecraft; and small chemical space propulsion systems. In the sciences, JSC is the lead center for life sciences, which include human physiology, operational medicine, and clinical medicine; and meteoritic and surface sample analysis for solar system exploration. JSC also has a supporting role in the microgravity sciences.

Future missions, such as are anticipated for human exploration of space, will require systems that can operate for long periods of time in a reliable and cost-effective manner. For this to happen, a plan based on newer technology rather than upgraded old capabilities is envisioned as the most feasible one. The significance of technology and associated research, in the overall conduct of our Nation's program, was discussed in the December 1990 report by the Advisory Committee on the Future of the Space Program. Under General Concerns, this report states, "Next to the talented people and a culture of excellence, the most important underpinning of the civil space program is its technology base." JSC has outlined two key roles in meeting the technology needs of space exploration. First, JSC will ensure that technologies are available when needed. Second, JSC will develop needed technologies that are unique to the Center missions and in those areas where JSC has particular expertise, experience, or facilities. The critical technology and application areas identified for future JSC programs and those areas where JSC intends to lead are given in figure 1. One of the key objectives of JSC strategy is to give employees opportunities to develop enhanced technical expertise and project management skills by defining, designing, and developing in-house projects that fit within the scope of the Center strategy for the future. The JSC R&T efforts provide the critical avenue to fulfill this objective.

This report serves to communicate within and outside the Agency our significant R&T efforts, as well as to inform Headquarters R&T program managers and their constituents of the significant accomplishments that have promise in future Agency programs. While not inclusive of all R&T efforts, the report represents a comprehensive summary of JSC activities, with the corresponding technology focal points identified in the Index.

The JSC R&T annual report is organized in five sections:

- The Life Sciences section provides a synopsis of space- and ground-based activities that address issues related to crew health and productivity during extended flights and on planetary surfaces. Substantial understanding of human physiology in space was achieved with the successful completion of SLS-1, the first dedicated life sciences Spacelab mission. The ground-based activities included projects on cell biology, immunology, and endocrinology to identify, at the molecular level, factors that contribute to physiological adaptations to the space environment. In other investigations, devices were developed and tested to ensure the habitability of spacecraft. These included presence of hydrazines and combustion products and selected bacteria. The understanding of factors for decompression sickness, susceptibility to space sickness, and biomedical risks associated with long-term spaceflight continues to be an important part of the JSC life sciences program.

- The Human Support Technology section includes projects on a variety of disciplines to ensure safety and high productivity of humans in space or on planetary surfaces. Several projects concerned with the use of computers in the training and task execution by humans are described. The objective of these efforts is to increase productivity, accuracy, and cost-effectiveness. Projects on expert systems used to track humans and resources, human-computer interface, and aids for remote operations are included. In addition, work related to several projects on user-intelligent system interaction, artificial intelligence, neural

	Overview	Technologies and capabilities
Human support	Technologies required to sustain human life and provide productive environment for mission operations, spacecraft systems, and planet surface systems	Regenerative life support* EVA suits and personal life support systems* Low gravity effects and countermeasures* Human factors* Crew health maintenance* Radiation health research* Thermal control*
Mission operations	Technologies to integrate control of mission between ground, spacecraft, and planet surface	Space systems monitoring and control* Automated crew and operator training* Software/design/engineering/reengineering* Flight design and preparation automation* Operations engineering process and software tools Mission control display and graphics* Automated requirements design tools
Spacecraft systems	Technologies necessary to build and operate higher quality human spacecraft with improved safety, reliability, and cost effectiveness for longer duration missions	Aerobraking* Automated operating systems* Vehicle health maintenance* Adaptive guidance, navigation, and control* High-definition video Automated on-orbit operations* Autonomous landing* Debris and meteoroid modeling and protection* Advanced power and propulsion High data rate communications
Planet surface systems	Autonomous, highly reliable, long-duration planetary surface system technologies providing capabilities for mission implementation	Habitat concepts and subsystems* Survey, mapping, and remote sensing Surface guidance, navigation, and control Robotic tracking and control Radiation protection* In situ resource utilization* System automation and maintenance On-orbit/surface assembly, and construction* Science instruments Surface dust countermeasures*
Management tools	Technologies required to improve the efficiency and effectiveness of program management and operations	Requirements documentation and control Configuration control Scheduling Design knowledge capture Budget management • Improved cost estimation algorithms • Real-time cost tracking • Correlation of technical and cost progress • Cost to completion estimates Software commonality

*JSC lead center or major contributor for technology development.

Figure 1. Technologies required for future JSC programs.

system interaction, artificial intelligence, neural networks, and applications of fuzzy logic in support of crew and mission support teams are described in this section.

- Solar System Sciences contains a sampling of the projects in support of manned exploration of the solar system. It includes new investigations of meteorites, cosmic and planetary dust, Earth orbital debris, remote sensing of the Earth, space radiation environment, analysis of lunar and planetary material, and origin and evolution of planetary structure. These projects are intended to support a fundamental space research program in Earth orbit, as well as a planetary exploration program having goals that include establishment of a lunar outpost and human mission to Mars.
- The Space Systems Technology section encompasses projects on control and guidance; materials and structures; automation and robotics; on-orbit assembly; construction and servicing; life support; propulsion; power; thermal; communications; and tracking systems. JSC continues to make outstanding contributions in the evolutionary, emerging, innovative, and mission-driven technologies in these areas.
- The Space Transportation Technology section contains projects on human support systems and space operations associated with the Agency's transportation infrastructures. Projects on closed-loop life support systems, deemed necessary to the Agency's long-range program, are highlighted. Projects that demonstrate significant progress in the design and development of human spacecraft and associated technologies are included in this section.

This report represents the coordinated effort of several JSC line organizations, most notably the Administration, Information Systems, Space and Life Sciences, Mission Operations, and Engineering Directorates. The schedule for this report provides a formidable challenge in that most of the work was to be completed in the months of December 1991 and January of this year. The authors of the individual reports are, therefore, commended for their timely efforts. In addition to the undersigned, the colleagues listed below coordinated specific sections of this report and provided the summary preceding their sections. Detailed questions should be directed to me, the section coordinators, or the principal investigators listed in the Index.

Lakshmi Putcha, Ph.D., Code SD, Life Sciences – (713) 483-7760

Barbara Woolford, Code SP, Human Support Technology – (713) 483-3701

Thomas Wilson, Ph.D., Code SN, Solar Systems Sciences – (713) 483-2147

Kumar Krishen

Kumar Krishen, Ph.D
Chief Technologist

Contents

Section I

Life Sciences

Summary

Life Sciences Summary

Emphasis in life sciences research at Johnson Space Center, NASA's lead center for the Life Sciences, has begun to shift toward ensuring crew health and productivity during extended flights in preparation for a permanent human presence in space. Substantial progress in understanding human physiology in space was achieved with the successful completion of SLS-1, the first Spacelab mission completely dedicated to life sciences research. Results from experiments performed on this mission, now under analysis, will provide much-needed baseline information on biological responses to spaceflight. Habitability requirements were delivered for both the Shuttle and Space Station Freedom Programs. The scope of countermeasures to protect space crews from physiological deconditioning was expanded to include 90-day flight envisioned for the new Long-Duration Orbiter Program.

Progress continues in the Extended Duration Orbiter Medical Projects (EDOMPs) mission to identify and correct potential decrements in crew health and performance during extended Orbiter flights. At present, the EDOMP focuses on enhancing the ability of Shuttle crews to land and to exit the vehicle safely after flights of up to 16 days in duration. Ongoing research efforts in defining and—as necessary—countering cardiovascular, muscular, neurological, gastrointestinal, and metabolic adaptations to the spaceflight environment are being pursued actively under this program. The requirements and medical standards established by the EDOMP will form the basis for 90-day missions, with the ultimate goal of extending the human presence in space safely to long Space Station tours, planetary exploration, and beyond.

Ground-based activities this year included biotechnological advances in the development of a fully automated cell culture system. This system, designed to simulate some of the fluid-mechanical conditions of microgravity, can also be used in space to raise high-fidelity tissue models and other applications. Basic research projects in cell biology, immunology, and endocrinology seek to identify, at the molecular level, factors that contribute to physiological adaptations to the space environment.

New noninvasive methods of measuring gastrointestinal function and human energy expenditure were adapted for spaceflight and verified during ground-based microgravity simulations. Magnetic resonance imagery was used successfully to verify that muscle mass in humans can decrease after as few as 9 days in flight. Physiological equipment developed for use in flight included electronic vision-occlusion goggles for testing visual-vestibular function and a noninvasive cardiovascular function monitor. Devices designed to ensure the habitability of spacecraft included atmospheric monitors for the presence of hydrazines and combustion products, and kits to detect the presence of selected bacteria. Statistical predictors were developed for decompression sickness and for susceptibility to space sickness; finally, expert systems are being identified to assess and counter the biomedical risks associated with long-term spaceflight.

Further details of these advances in life sciences activities are offered in the following articles.

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Section I

Life Sciences

Signficant Tasks

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A Simple Noninvasive Method for Determining Gastrointestinal Function

TM: **Lakshmi Putcha, Ph.D./SD4**
PI: **Robert P. Hunter, M.S./KRUG**
Reference: **LS 1**

The combined effects of decreased fluid consumption and increased fluid loss in microgravity may induce changes in gastrointestinal (GI) function, which, in turn, result in poor absorption of nutrients and other substances. The fluid redistribution in microgravity may also affect absorption and gastric emptying. Anecdotal data from U.S. and U.S.S.R. space missions suggest that GI motility and function are altered during spaceflight. Preliminary investigations suggest that absorption of therapeutic agents such as acetaminophen is variable during flight, and that this variability depends upon length of time in flight. Although some reported symptoms such as loss of appetite, frequent constipation, and decreased bioavailability of orally administered medications imply that GI function is decreased, direct measurements of GI motility and function are, as yet, unavailable. Most clinical methods of assessing GI function are invasive and require special technical expertise and equipment. Recent development of a noninvasive method that can measure GI motility indirectly as a function of mouth-to-cecum transit time (MCTT) prompted exploration of this method for use during flight.

The noninvasive method relies on measuring exhaled hydrogen after consumption of lactulose, a fermentable carbohydrate that is not absorbed in the small intestine. Bacteria in the large intestine (cecum) ferment this sugar, so the rate at which the hydrogen produced by that fermentation appears in the breath can be used to calculate the time it takes for the lactulose to pass from the mouth to the cecum. The present investigation describes evaluation of the validity and sensitivity of lactulose-breath-hydrogen analysis for detecting changes in GI transit time during antiorthostatic bed rest.

Six healthy volunteers performed the test four times each, twice before and twice during a 10-day head-down bed rest period. After an overnight fast, subjects consumed 20 g of lactulose syrup, and supplied breath samples every 10 minutes for 4 hours thereafter. Breath-hydrogen concentrations were analyzed with a Quintron Microlyzer. MCTT was calculated as the time from consumption to appearance of a consistent rise in hydrogen concentration in three consecutive breath samples. Changes in MCTT were taken to reflect changes in GI motility. MCTT values obtained from each subject are presented in table I; mean MCTT values are presented graphically in figure 1.

Mean MCTT was significantly different ($p < 0.05$) during the ambulatory and the bed rest periods. The 63% increase in the MCTT during bed rest, reflecting decreased GI motility, supports earlier reports of reduced GI function during bed rest as indicated by symptoms such as lack of appetite and constipation. The lactulose caused no untoward GI effects, and appears to be a safe and sensitive method for determining GI motility during flight. Direct information on GI motility will be invaluable in developing and testing nutritional and pharmacological countermeasures, as well as providing information on how spaceflight affects the physiology of the GI tract. Determining the degree and magnitude of GI changes as a function of mission duration will be essential in assessing crew health and performance during Space Station missions, lunar and Mars explorations, and other long space missions.

TABLE I. EFFECT OF BED REST ON GASTROINTESTINAL MOTILITY IN NORMAL SUBJECTS

Subject no.	MCTT Control	MCTT Bed rest
S1	67.5	55
S2	70	110
S3	70	145
S4	100	135
S5	95	175
S6	55	105
Mean ± SD	74.09 ± 19.85	120.83 ± 42.31

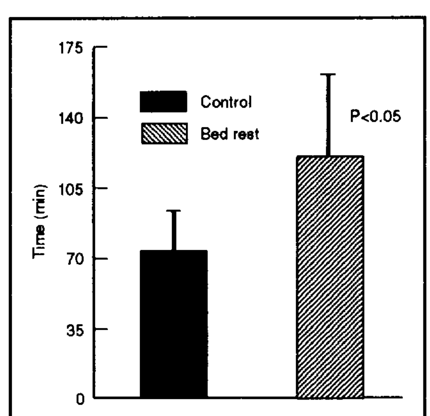

Figure 1. Mouth-to-cecum transit time (MCTT) of lactulose in normal subjects.

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Chemiluminescent Oligodeoxynucleotide Probes for the Rapid Detection of Bacteria in Water and on Surfaces

TM: Duane L. Pierson, Ph.D./SD4
PI: Saroj K. Mishra, Ph.D./KRUG
Reinhardt A. Rosson/BioTechnical Resources, WI
Laura Mallary/KRUG

Reference: LS 2

During long spaceflights, it will be necessary to have the capability to quickly determine the microbial quality of recycled water and spacecraft surfaces. Current tests for detecting, enumerating, and identifying bacteria are labor-intensive, time-consuming, and not ideal for use in microgravity. Nucleic acid hybridization offers a possible means for rapid assessment of microbial populations in a spacecraft environment. Rapid, sensitive tests based on the hybridization of short, chemiluminescent oligodeoxynucleotide probes (fig.1) are currently under development through a NASA Small Business Innovation Research grant to Bio-Technical Resources. The Phase I effort has demonstrated the feasibility of using chemiluminescent probes as a means of detecting and enumerating bacterial populations, and has resulted in the isolation of probes for the determination of total bacteria, selected groups of indicator organisms (such as coliforms), and specific species of bacteria (such as *Escherichia coli*).

A probe is a short nucleic acid sequence that has been found to be uniquely complementary to a genetic sequence in a specific group of organisms. When the probe is exposed to the complementary target nucleic acid, the two sequences hybridize. A chemical reporter compound is attached to the probe so that hybridization can be easily detected. Of the commercially available, nonradioactive reporter compounds, chemiluminescent biotin-avadin conjugates are among the most promising. These methods require the hybridization of a biotinylated probe to the target nucleic acid. After removal of an unhybridized probe, a strepavidin-alkaline phosphatase conjugate is bound to the biotin groups. Reaction with alkaline phosphatase substrate results in an emission of light proportional to the amount of alkaline phosphatase bound to the hybridized probe. The light emission is detected and quantified using a photodiode photometer.

Proposed Phase II development efforts will focus on the advancement of rapid chemiluminescent oligodeoxynucleotide probes to assess microbial populations in water and surface samples on Earth and in space. These sensitive tests will directly detect and quantify total and specific bacteria in environmental samples. Whole-cell hybridization procedures will be developed, facilitating quantitative tests that do not require extraction of the target nucleic acid sequences from the bacterial cell.

Current technology for determinating the numbers and types of bacteria in water and on environmental surfaces involves procedures that are not practical in a spaceflight environment. The techniques under development are rapid, can be automated, require few supplies, and offer excellent sensitivity and specificity. These procedures can be adapted easily to a variety of specific microbial detection, enumeration, and identification uses. This innovative, real-time test system will facilitate environmental monitoring in closed-loop water distribution systems on spacecraft and will enhance monitoring of water supplies on Earth as well.

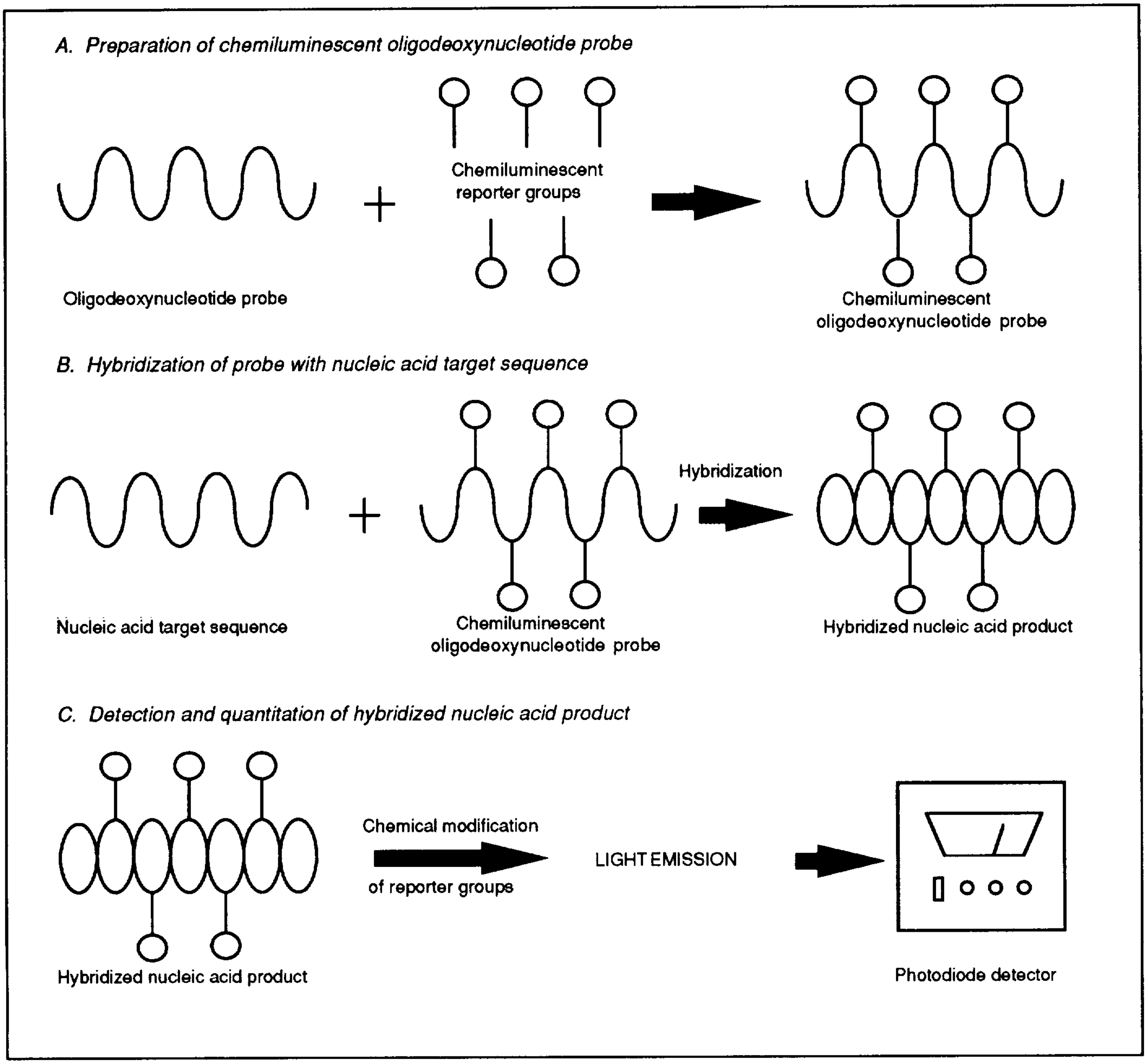

Figure 1. Chemiluminescent oligodeoxynucleotide probe hybridization.

A Combustion Products Analyzer for Contingency Use During Thermodegradation Events on Spacecraft

TM:	**John T. James, Ph.D./SD4**
PI:	**Thomas F. Limero, Ph.D./KRUG**
	Steve Beck/KRUG
	Raymond C. Cromer/Exidyne
	Steve Summerfield/Exidyne
Reference:	**LS 3**

The Toxicology Laboratory at the Johnson Space Center (JSC) along with Exidyne Instrumentation Technologies (EIT) have developed a combustion products analyzer (CPA) to monitor combustion products from a thermodegradation event in real time on board spacecraft. The term "thermodegradation," as used in this paper, refers to the full range of events from an overheated electrical component or wire to a major fire. This development effort has been driven by small incidents on the Space Shuttle. After an incident aboard STS-28 in which a section of teleprinter cable insulation was thermally degraded, flight rules were modified to state that in the event of a combustion incident of "moderate size," unless it can be determined that the cabin atmosphere is safe to breathe, the crewmembers will deorbit and prepare to land at an emergency landing site if necessary. Developing a means of measuring air quality on board, immediately following a thermodegradation incident, was seen as a means to minimize the chance of performing a risky emergency landing. The CPA was developed accordingly.

The CPA monitors four gases that are the most hazardous compounds (based on toxicity potential and quantity produced) likely to be released during thermodegradation of synthetic materials: hydrogen fluoride (HF), hydrogen chloride (HCl), hydrogen cyanide (HCN), and carbon monoxide (CO). The levels of these compounds serve as markers to assist toxicologists in determining when the atmosphere is safe for the crew to breathe following a thermodegradation event.

The CPA has four electrochemical sensors (fig. 1), one for each gas, and a pump to pull air over the sensors. The electrochemical sensors of the CPAs are unique in their size and zero-g compatibility. The immobilized electrolytes in each sensor permit the instrument to function in space and eliminate the possibility of electrolyte leaks. The sample inlet system of the CPA is equipped with a particulate filter that prevents clogging from airborne particulate matter. Other features include a digital readout that displays gas concentrations and various warning signals (low battery, low flow). The instrument can be set to scan the concentrations of all four gases, or it can monitor one gas continuously.

The CPA was first flown on STS-41 in October 1990, and has flown on all subsequent missions, including STS-38, STS-35, STS-37, STS-39, STS-40, STS-43, STS-48, and is manifested for STS-44. During these missions, the CPA has been destowed and daily readings have been recorded for each sensor to assess the on-orbit operation of the sensors. Additionally, the ability of the sensors to remain calibrated through the rigors of launch and mission duration have been evaluated by postflight analyses.

Results, to date, indicate that three of the sensors have performed nominally on orbit and have remained in calibration during the course of the mission. The daily readings of the HCl, HCN, and HF sensors (fig. 2) have remained very low during these missions, indicating that cross-reacting chemicals that might interfere with these sensors are not present during nominal operations. Sensor performance is apparently not affected by lift-off or microgravity. During STS-41, the daily CO sensor readings increased from approximately 5 ppm to 45 ppm. Postflight analyses of grab samples collected during the mission found much lower concentrations of CO than those obtained in flight using the CPA. Additionally, hydrogen was found in significant quantities (~80 ppm) in the grab samples. Subsequent testing at JSC verified that exposing the CPA to a hydrogen concentration of 100 ppm produced results similar to those found during STS-41 (approximately a 2:1 response). Furthermore, the CO sensor reading continued to drift upward on continued exposure to hydrogen.

As a result of the data obtained on STS-41 and subsequent testing, EIT and the Toxicology Laboratory embarked on a program to modify the CO sensor to reduce the cross-sensitivity to hydrogen and to stabilize the response. Considerable improvements in the response stability and cross-sensitivity ratio (approximately 10:1) to hydrogen were accomplished by elevating the voltage bias of the working electrode with respect to the reference electrode in the electrochemical cell. These modifications resulted in a CPA CO sensor that has a much improved cross-sensitivity to hydrogen and responds to hydrogen in a "well-behaved" predictable manner (fig. 3). The modified sensor has flown on all missions since STS-37. These improvements in the CO sensor greatly increase its value as a trend indicator in the event of a thermodegradation event.

Ongoing efforts in the development of the CPA include the incorporation of a microprocessor to provide more signal-processing capability, testing of the CPA in an atmosphere containing thermodegradation products of spacecraft synthetic materials, and the development of a hydrogen sensor. The hydrogen sensor, in conjunction with the microprocessor, will be used to totally compensate the CO reading for the presence of hydrogen. These efforts have begun and are scheduled for completion in approximately 1 year.

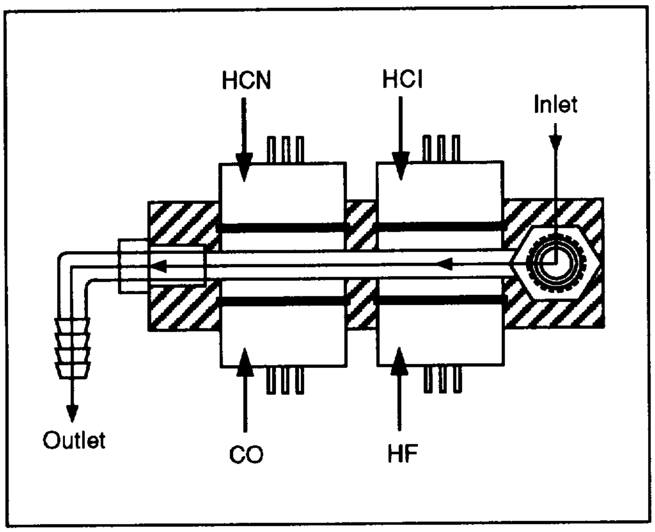

Figure 1. CPA sensor block.

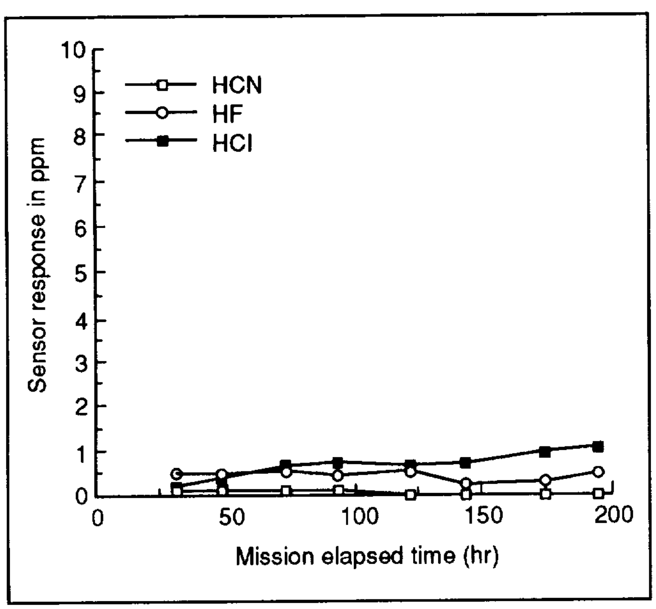

Figure 2. CPA response on STS-40.

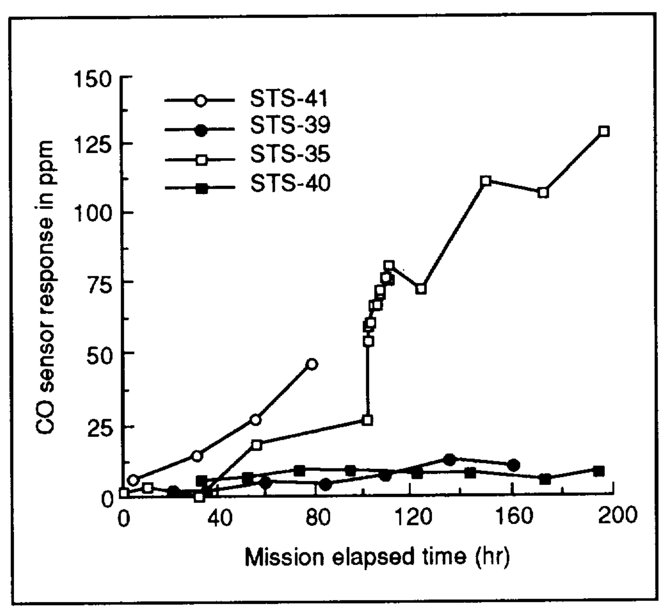

Figure 3. Comparison of CO response.

Ion Mobility Spectrometry: Development of a Monitor to Detect Hydrazine Rocket Fuels in the Airlock after Extravehicular Activities

TM: John T. James, Ph.D./SD4
PI: Thomas F. Limero, Ph.D./KRUG
John H. Cross, Ph.D./KRUG
Steve Beck/KRUG
Gary Eiceman, Ph.D./New Mexico State University
John Brokenshire, Ph.D./Graseby Ionics, Ltd., Watford, U.K.
Colin Cumming/Graseby Ionics, Ltd., Watford, U.K.
Reference: LS 4

Hydrazines are acutely toxic and carcinogenic compounds used as rocket fuels in military and space applications. Monomethylhydrazine (MMH) is used in the orbital maneuvering system and reaction control system of the Space Shuttle. Hydrazine (HZ) has been selected as the fuel for Space Station Freedom and is often used in satellite propulsion systems. The potential exists for hydrazines to contaminate an astronaut's space suit during extravehicular refueling, thus inadvertently introducing hydrazines into the airlock at the end of the extravehicular activity (EVA). The potential presence of these compounds must be detected before opening the airlock to the Station interior. Because hydrazines are highly reactive, detecting them at their 7-day spacecraft maximum allowable concentrations is difficult (HZ, 0.04 ppm; MMH, 0.002 ppm).

Developing instruments that are sensitive at the parts-per-billion (p/b) level, that respond quickly, and are portable represents a significant challenge. Draeger tubes and electrochemical sensors are used at present to detect hydrazine contamination in spacecraft airlocks; neither technology is sufficiently sensitive to detect very small concentrations. The emergence of ion mobility spectrometry (IMS) as a sensitive, reliable, portable, real-time technique for detecting chemical warfare agents spurred interest in applying IMS to the measurement of hydrazines. Preliminary studies of a Graseby Ionics IMS field instrument showed that it could detect HZ and MMH at the p/b level, although response and recovery times were longer than desirable, and the presence of ammonia interfered with compound identification. This report addresses efforts this year to produce a monitor for hydrazines that can meet the required criteria.

The principle of IMS is illustrated in figure 1. As ambient air is pulled across a membrane, airborne compounds cross that membrane and are carried into an ionization region where reactant ions transfer a charge to the sample molecules. The ionized sample molecules are then pulsed into a drift region where they separate according to charge density. Ions can be identified by their characteristic drift times. Degree of selectiveness can be determined through selection of reactant ions generated in the ionization region.

The first step in developing a monitor specifically for hydrazines was to find a "dopant" that would generate the appropriate reactant ions. Reactant ions from 5-nonanone produced HZ, MMH, and ammonia ions that were sufficiently separable to allow analytical identification (fig. 2). Other potential interferents, such as Freons, did not interfere with detection of hydrazines. With this improvement in hydrazine selectivity, two Graseby field units were modified to operate with 5-nonanone, dataloggers were added to record results, and this unit was flown on STS-37 in April 1991 to monitor hydrazines on orbit.

Objectives during this flight included evaluating calibration stability during launch, flight, and reentry; assessing operation during EVAs; estimating the effect of ammonia in the Shuttle atmosphere on detection of hydrazines; and identifying other compounds in the Shuttle atmosphere that might interfere with hydrazine detection.

The unit was calibrated at five points (HZ) or six (MMH) points before launch and after landing. Calibration curves made before and after STS-37 were nearly identical, demonstrating instrument ruggedness. The lowest concentration recorded was 9 p/b MMH, which is in the range of the new exposure limits. The upper limit of detection was about 600 p/b. Linear relationships (fig. 3) were found across the entire range for both HZ and MMH.

During flight, data were collected at three locations on five occasions for a total of 15 data sets. One sample was taken early in the mission when the cabin pressure was 14.7 psia. Other samples were taken at 10.2 psia during EVAs. Changes in cabin pressure shifted the reactant ion peak; in a postflight experiment, drift time was found to be linear and directly proportional to pressure. Response and recovery times were longer than hoped, probably because the polar hydrazines adsorb readily on surfaces within the instrument.

Because ammonia is a product of human metabolism, its concentration is expected to increase throughout manned flights; however, since ammonia is polar and reactive, its presence in the spacecraft atmosphere has been difficult to characterize. Several flight data sets collected at 10.2 psia showed a small peak at the calculated drift time for ammonia; however, this peak was unlikely to interfere with detection of a hydrazine. No other interfering compounds were detected in any data set. Small peaks did appear before the reactant ions in two data sets, but no significant peaks appeared consistently within the range of drift times for the hydrazines.

A second flight experiment will test instrument performance during longer sampling periods. Verification of the internal consistency of instruments used for long periods without maintenence will help ensure that hydrazines are identified correctly in the Shuttle atmosphere. Data from these two flight tests will be used to construct flight hardware for use on all missions during which EVAs will be performed.

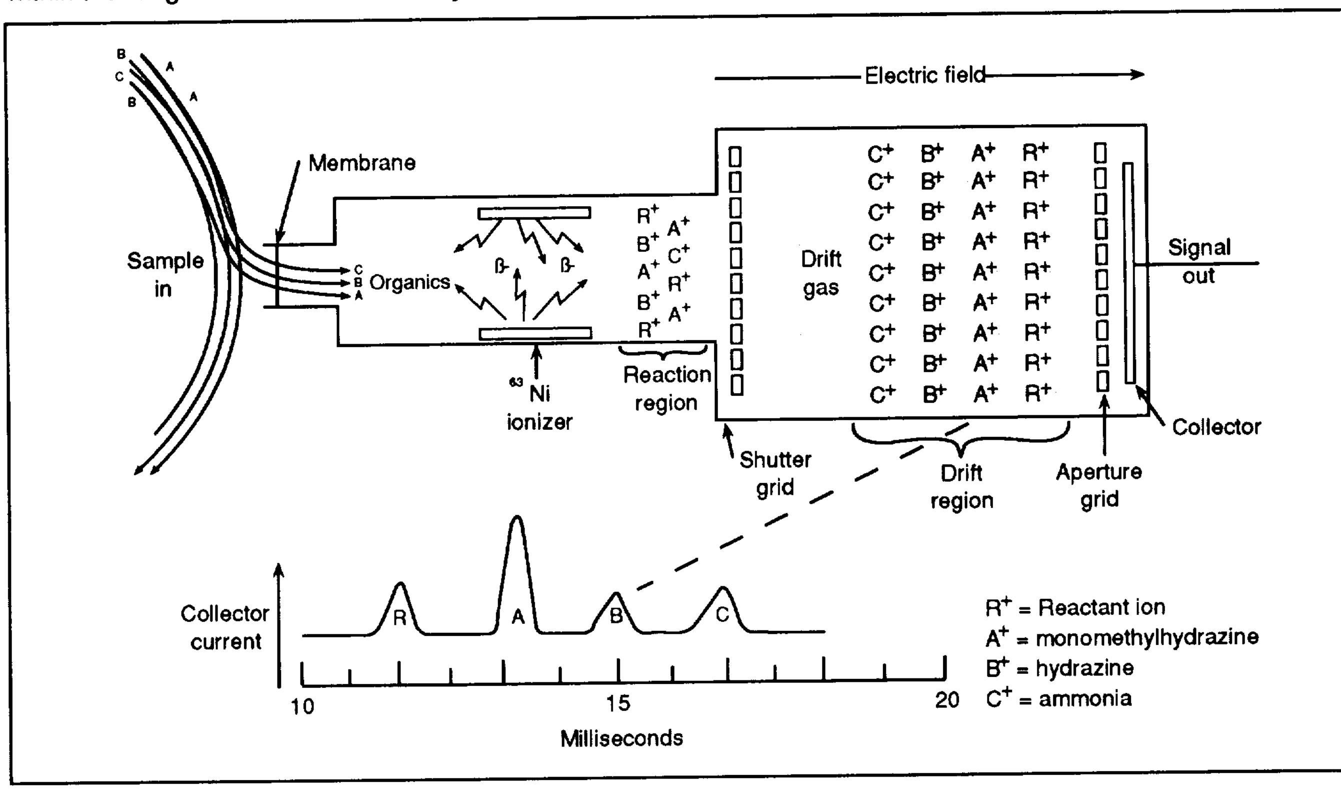

Figure 1. Principles of ion mobility spectrometry.

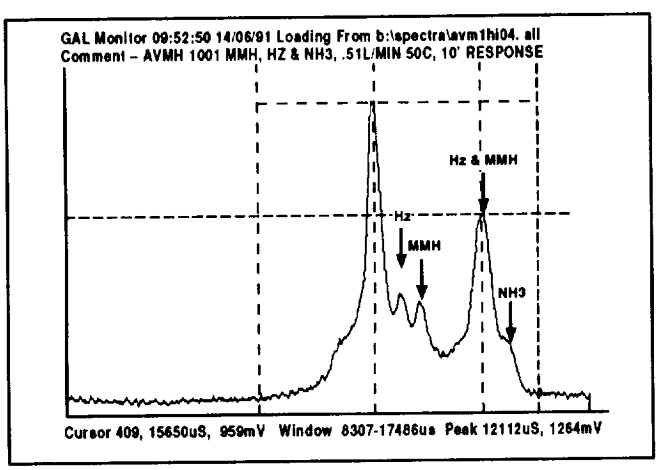

Figure 2. Ion mobility spectrum.

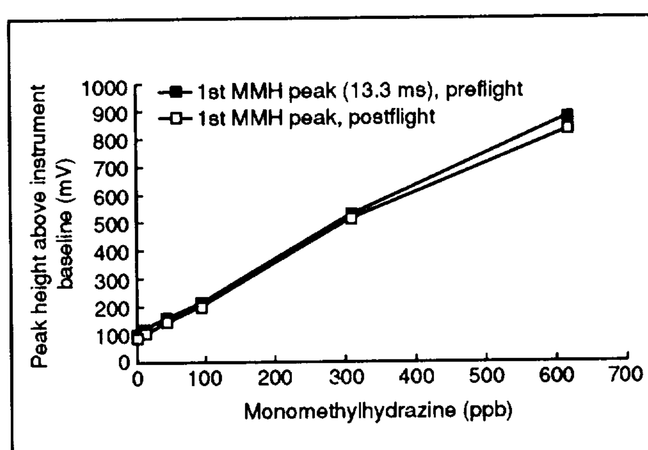

Figure 3. MMH AVM calibrations.

Magnetic Resonance Imaging of Skeletal Muscles

TM: Mazher Jaweed, Ph.D./SD4
PI: William Fortner, Ph.D./KRUG
Pandanna Narayana, Ph.D./UTHSC, Houston
Adrean LeBlanc, Ph.D./Baylor College of Medicine, Houston

Reference: LS 5

Prolonged exposure to microgravity causes a loss of muscle strength, increased fatigue, and significant muscle wasting (atrophy). These factors are believed to have a negative effect on the functional capacity of the astronauts in space as well as on Earth after their return to a one-g environment. Experimental studies with rats have shown that exposure to zero g for 12 days produces alterations in muscle fiber-type composition, decreased capillarity, and membrane damage. Unfortunately, similar data are not available in astronauts because muscle biopsy data are lacking. However, clinical diagnostic tools, such as magnetic resonance imaging (MRI), can measure precisely the leg and muscle volumes before and after flight (figs. 1 and 2).

MRI is a noninvasive method that provides excellent nondestructive images of soft tissue in the body, such as brain, spinal cord, and muscle tissue. In principle, the nuclei (protons) of water and lipid molecules are excited by imposing a high magnetic field by radiofrequency in the desired region of the muscle. Usually this field is 1.0 or 1.5 tesla (by comparison, the Earth magnetic field is 5×10^{-5} tesla). The images are obtained from the spectrum of excitation and relaxation of protons in relationship to water in the tissue. The bright or lighter parts will indicate relatively prolonged relaxation time (fats, bone marrow); whereas the darker areas have a shorter relaxation time (muscle, fascia) (fig. 3).

The protocols of a detailed supplemental objective were implemented. Eight astronauts from STS-35 and STS-40, who undertook 9 days of space mission, were tested for leg and calf muscle volumes by MRI. Images were obtained in 2 to 3 sessions before flight and twice after flight: 2 days (R+2) and 7 days (R+7) after return to one g. These images included thirty to forty, 5-mm thick axial views of the leg between the knee and ankle. The cross-sectional area (CSA) of the muscles and the leg were measured by computerized planimetry; and statistical comparisons were made. Compared to preflight, the CSAs at R+2 days were significantly lower (9 to13%, $P < 0.05$). There was no significant change between R+2 and R+7 days values (fig. 4).

These data indicate that 9 days of spaceflight may significantly decrease the leg and muscle area in the lower extremities of astronauts. However, it is doubtful whether this decrease in area is purely due to muscle atrophy. During spaceflight, the astronauts' body fluids are shifted towards the head; a total redistribution is not complete until 7 to 14 days after return to Earth. Therefore, it is proposed that the loss of muscle CSA of the leg and muscles in lower extremities may be due to a combination of muscle atrophy and incomplete redistribution of body fluids. Future studies are warranted to elucidate these interactions.

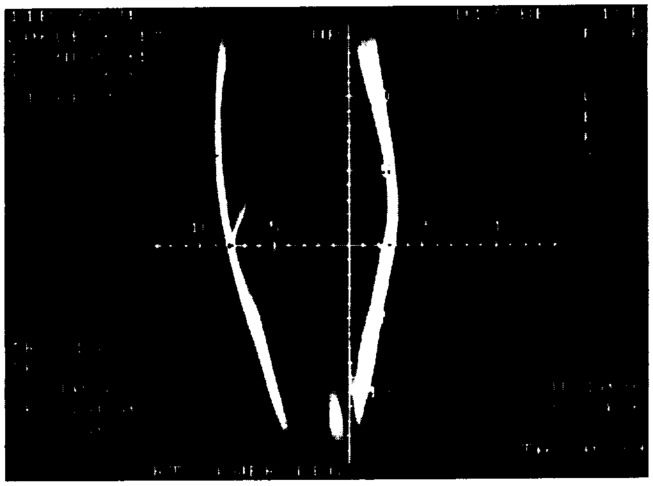

Figure 1. Coronal MRI scan of right leg of a male volunteer showing the region of interest (–10 to 10 on vertical scale), where the data were collected.

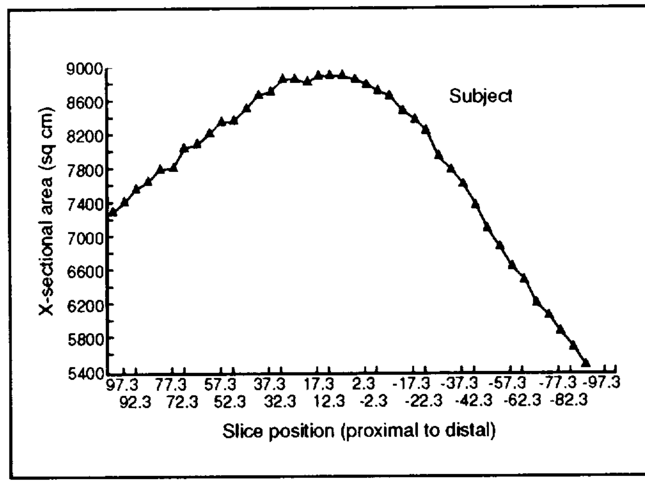

Figure 2. Volume of whole right leg in the region of interest. Each measurement point represents CSA (cm^2) of the entire calf.

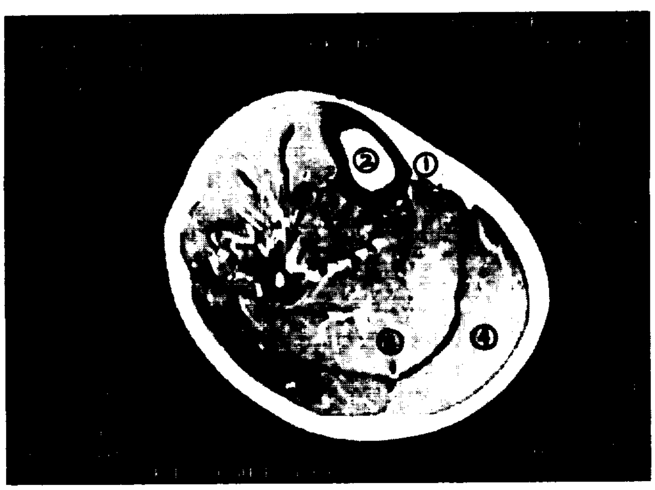

Figure 3. Axial MRI scan of the leg of a healthy male subject showing different tissue: (1) subcutaneous fat, (2) bone marrow, (3) soleus muscle, (4) medial gastrocnemius muscle, (5) lateral gastrocnemius muscle, and (6) tibia and fibula.

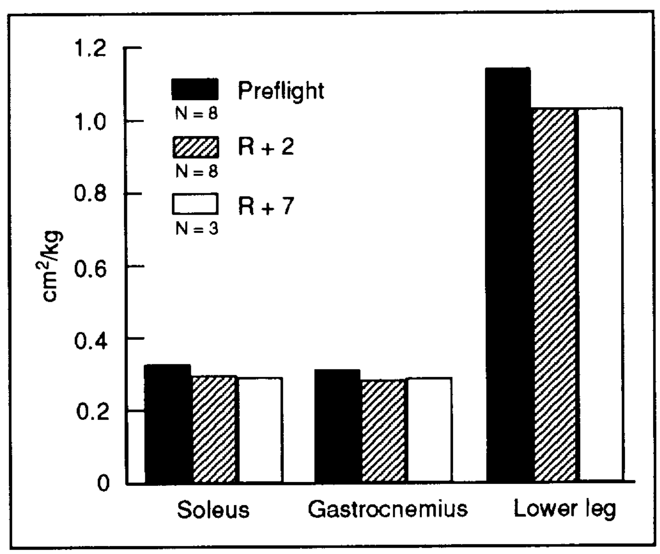

Figure 4. Average cross-sectional areas of 30 to 40 slices of the soleus, gastrocnemius, and the whole leg, pre- and postflight. All values were normalized by dividing the CSAs in cm^2 with the body weight in kg.

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B-Cell Radiosensitivity and Protection by Cytokines

TM: **Clarence F. Sams, Ph.D./SD4**
PI: **David G. Ritchie, Ph.D./KRUG**
Peggy A. Whitson, Ph.D./SD4

Reference: **LS 6**

Cells involved in the immune response are derived from bone marrow stem cells. During their normal course of development and differentiation into immunoreactive cells, these stem cells must undergo multiple cell divisions. Once they become mature, however, this process of cell division is temporarily interrupted and the newly matured immune cells become quiescent while they await antigenic stimulation. Following antigenic stimulation, several recently discovered naturally occurring hormones, termed cytokines, then participate in the development of immunocompetent antibody-producing cells by acting to accelerate quiescent cells (termed G_0) into dividing cells that are actively synthesizing DNA (termed S-phase). Quiescent cells have long been known to be highly radiosensitive as compared to S-phase cells. This radiosensitivity (particularly during long-duration spaceflights) could lead to immune suppression that, in turn, could severely limit the mission goals or threaten crewmembers' lives. Given the known natural role of cytokines in promoting immunocompetence, it should also be possible to determine whether particular cytokines might also act as radioprotectants by using purified human antibody-producing cells or B lymphocytes in an *in vitro* experimental system.

Preliminary studies directed toward cytokine effects on B-cell radiosensitivity were begun using purified peripheral blood B cells obtained from normal human volunteers. Red blood cells and granulocytes were removed by centrifugation through a density gradient. The remaining lymphocyte fraction (which contained T cells, monocytes, and natural killer T cells in addition to B cells) was then incubated with monoclonal antibodies specific for non-B cells. The final purified B cell fraction (obtained after lysis of most non-B cells) was then stained with fluorescent-conjugated monoclonal antibodies for B and T cells and analyzed by flow cytometry, a technique that examines the fluorescent intensity of each cell. This purified B cell fraction contained 80% $CD20^+$ (B cell); 20% $CD3^+$ (T cells); and less than 0.1% monocytes. To artifically activate these quiescent cells, we tested a variety of known B-cell activating agents including anti-IgM, anti-IgM/cytochalasin B(CB), anti-IgM/TPA (phorbal ester), and *S. aureus* Cowans I (SAC). After incubation for 72 hours, tetrazolium salt (MTT) was added during the final 2 hours of the assay. Results (fig. 1) demonstrate that MTT conversion was significantly enhanced by each of the test reagents, indicating that each of these reagents was successful in activating B lymphocytes. Using SAC activation, we next intend to determine the dose/dose-rate exposure to ^{137}Cs gamma radiation that will block B-cell activation. Finally, we will then determine the ability of specific recombinant cytokines (i.e., interleukins 1, 2, and 4) to modify B-cell radiosensitivity.

In a second study, we used a continuous human B-cell line termed CESS. These cells express different amounts of surface immunoglobulin (sIg) per cell on their cell surface. Because normal B-cell subpopulations are known to exhibit differential radiosensitivities, we were interested in asking whether this differential radiosensitivity might be due to the expression of different amounts of sIg among normal B-cell subpopulations. Using a "panning" technique, we were able to obtain sIg-rich CESS and sIg-poor CESS cell fractions that contained about 80 and 20% of sIgG-bearing cells, respectively, when measured by flow cytometry. Using a cloning assay, we then tested the radiosensitivity of two different sIg-rich populations (83 and 78% sIg^+) and two sIg-poor populations (27 and 14% sIg^+). As shown in figure 2, our preliminary results suggest that differences in the surface expression of IgG in transformed CESS cells do not significantly affect cell radiosensitivity.

The following conclusions were obtained from these studies:

- Human peripheral B cells can be activated under *in vitro* conditions and will provide a model system with which to study cytokine effects on B-cell radiosensitivity.
- Surface Ig expression on transformed human CESS cells does not affect cell radiosensitivity. Further studies using normal human sIgM-and sIgD-bearing B cells are needed to more fully address this question.

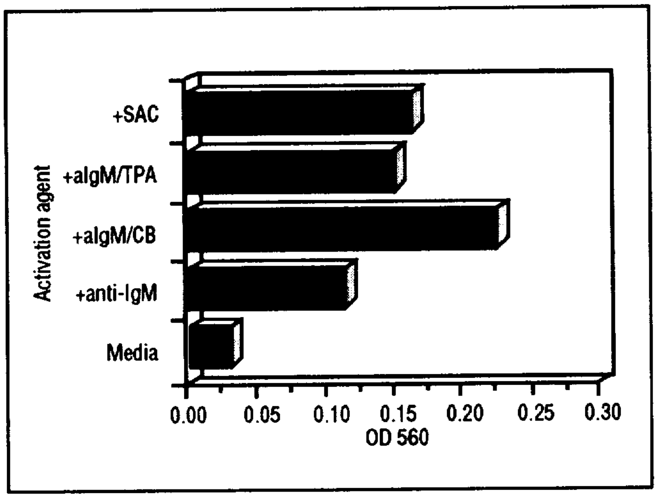


Figure 1. *In vitro* B-cell activation. Purified human B cells (10^5/well) were seeded into a 96 well round bottom plate. Twenty four hours later the following reagents were added to triplicate wells: anti-IgM (50 µg/ml); anti-IgM/CB (1 µg/ml); anti-IgM/TPA (50 µg/ml); and SAC (1:10,000 v/v). MTT was added during the final 2 hours of a 72-hour incubation and the OD_{560} was determined for each sample with an ELISA reader. Data represent the mean of triplicate samples.

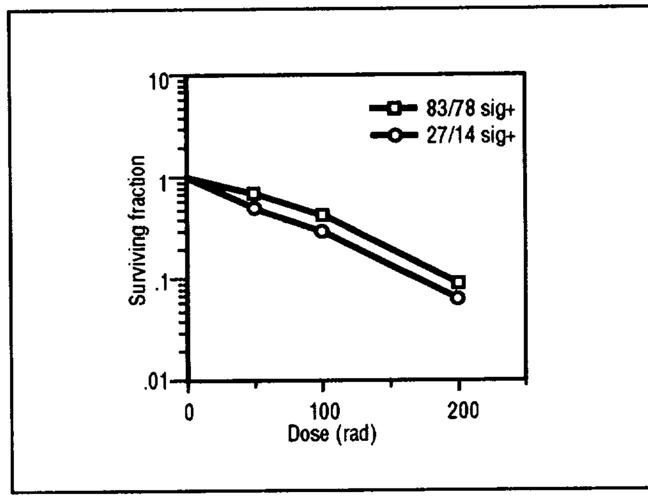


Figure 2. Effect of sIg expression on CESS radiosensitivity. Two sIg-rich CESS cell populations (83 and 78% sIg$^+$) were obtained by "panning" with anti-human IgG-coated plates. Non-adherent sIg-poor CESS cells (27 and 14% sIg$^+$) were also collected from the IgG coated plates. Each population was exposed to 0-200 rads of gamma irradiation from a ^{137}Cs source and plated out in soft agar. After 14 days, colonies of 50 cells or greater were counted and the surviving fraction for each population was calculated. Data represent the mean of each pair of sIg-rich and sIg-poor populations.

The Effect of Natriuretic Peptides on Prazosin Binding to Alpha1 Adrenergic Receptors in Mouse BC3H1 Cells

TM: Peggy A. Whitson, Ph.D./SD4
PI: W. Jon Williams, Ph.D./NRC
Reference: LS 7

Many of the physiological consequences of spaceflight (i.e., exposure to microgravity) have been well documented in the last 30 years. These include a redistribution of body fluids from the periphery to more central regions of the body. This central fluid shift results in several alterations in the neural-hormonal system—including plasma levels of catecholamines; of the antidiuretic hormone, aldosterone; and of atrial natriuretic peptide (ANP)—which serve as adaptational responses to microgravity. The physiologic adaptation to microgravity is thought to be responsible for the phenomenon of orthostatic intolerance (dizziness or fainting) that occurs in astronauts upon return to Earth. As this is considered to be a significant medical problem, a great deal of research has focused on the physiological mechanisms of orthostatic intolerance.

Found in the central nervous system, ANP is a member of a class of natriuretic peptides that is synthesized and released from the atrial tissue of the heart. When the atrial tissue stretches, for example, in response to increased central fluid shifts, ANP is released. ANP acts on receptors within the kidney to control fluid and electrolyte retention. It also acts on receptors within the walls of blood vessels, where it relaxes the vascular smooth muscle, decreasing the contractility of the heart, thus lowering blood pressure. ANP binding to receptors initiates an intracellular process that releases a so-called second messenger (cGMP) that mediates the cell responses to ANP stimulation.

Recently, ANP has been shown to relax muscle tissue that previously had been contracted with the neurohormone, norepinephrine (NE). Since NE is released from the sympathetic nervous system and constricts blood vessels, this work suggested that ANP may modulate either the peripheral autonomic system or the blood vessel response to signals from the sympathetic nervous system. However, the previous studies did not determine the nature of the interaction between natriuretic peptides and the target tissue. Therefore, a series of *in vitro* experiments was performed with several natriuretic peptides to determine how the binding of hormone to alpha1 adrenergic receptors is modulated by ANP.

Experiments were performed to determine how ANP affects prazosin binding to alpha1 adrenergic receptors. Prazosin is a drug that selectively binds to alpha1 receptors in a manner similar to the naturally occurring hormone, NE. Mouse BC3H1 cells, a tumor-derived cell line similar to vascular smooth muscle, were incubated with varying concentrations of ANP in the presence of prazosin. ANP decreased the binding affinity of prazosin in a dose-dependent fashion (fig. 1). This suggested that ANP could regulate the function of the adrenergic receptor. In addition, studies using various concentrations of dibutyl cGMP, a membrane-soluble analog of naturally occurring cGMP, was incubated with these cells in the presence of prazosin. Dibutyl cGMP inhibited prazosin binding to alpha1 adrenergic receptors in a concentration-dependent manner (fig. 2). Since cGMP is a known second-messenger of the guanylate-cyclase-linked ANP receptor, these data suggest that ANP modulates prazosin binding to alpha1 adrenergic receptors via this second messenger.

Several studies using other members of the ANP class of natriuretic peptides have demonstrated a similar ability to regulate prazosin binding to alpha1 adrenergic receptors. Future studies will use inhibitors of various intracellular enzymes involved in the cGMP process to pharmacologically dissect the mechanism of the action of natriuretic peptides on the sympathetic responses of smooth muscle.

Conclusions from these studies include the following:

- ANP and other natriuretic peptides appear to modulate the smooth muscle responsiveness to stimulation by the sympathetic nervous system via the alpha1 adrenergic receptor.
- Modulation of alpha1 adrenergic receptors by natriuretic peptides appears to be mediated through the intracellular second-messenger cGMP.

These studies provide evidence that ANP, a fluid/electrolyte regulating hormone, interacts with a specific aspect of the autonomic nervous system. Since recent data on Space Shuttle flights show that ANP is released during the early phase of flight, the interaction between natriuretic peptides and the sympathetic nervous system may have important effects on the cardiovascular deconditioning that occurs in space. Our data suggest that the release of ANP during a Shuttle mission may dampen the cardiovascular response to sympathetic nervous system stimulation.

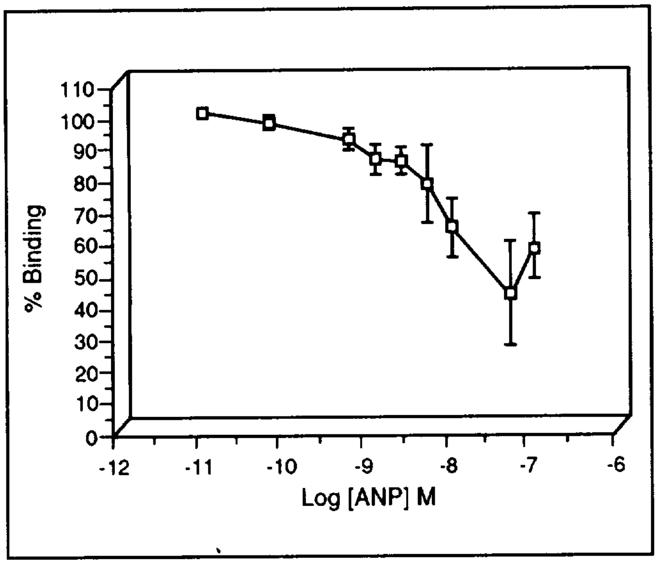


Figure 1. This figure shows the concentration-dependent decrease in prazosin binding in the presence of ANP. As the concentration of ANP increases, the degree of prazosin binding decreases.

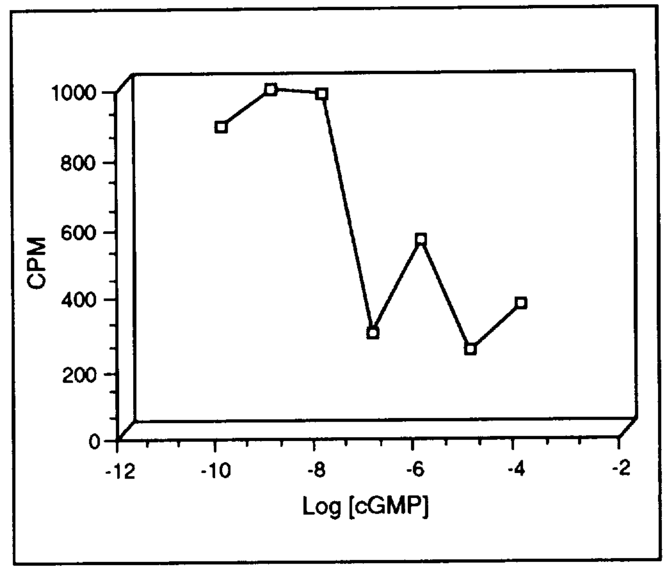


Figure 2. This figure shows the concentration-dependent decrease in prazosin binding in the presence of dibutyl cGMP, a membrane-soluble analog of the naturally occurring intracellular second-messenger, cGMP.

Endothelial Cells Degrade Atrial Natriuretic Peptide

TM: C. F. Sams, Ph.D./SD4
PI: P. A. Whitson, Ph.D./SD4
S. J. Frost/NRC
Reference: LS 8

One of the first observed changes in astronauts exposed to microgravity is the shift of body fluids from the lower body to the head and chest. The body responds to this fluid shift with several endocrine mechanisms that alter fluid and electrolyte (salt) balance. The result of these endocrine changes is decreased plasma volume and total body water, and increased excretion of sodium, potassium, and calcium. The loss of plasma volume has been correlated with orthostatic intolerance (fainting) when the astronauts return to Earth. Orthostatic intolerance is thought to be caused, at least in part, by the volume decrease that exacerbates lower than normal return of blood to the heart after reexposure to gravity.

One important endocrine factor involved in the loss of fluid and salt from the body is atrial natriuretic peptide (ANP). ANP increases sodium and water excretion by the kidney, while decreasing thirst and inhibiting the conservation of fluid. In simulated microgravity, ANP plasma concentration rapidly increases, with concurrent loss of water and salt. Early data from four Shuttle astronauts indicate that ANP levels in plasma increased after 2 days in flight and then decreased later in flight. Some physiological effects of ANP have also been observed early during flights, including decreased thirst, net loss of total body fluids, and a decrease in some volume-conserving endocrine factors.

To better understand the mechanisms involved in plasma volume loss, we have investigated how the degradation of ANP is regulated. Recently, we have discovered an enzyme on the surface of an endothelial cell line from the pulmonary artery, termed CPA47. This enzyme appears to degrade ANP; thus, ANP secreted from the heart would contact endothelial cells that line the pulmonary arteries, and would be removed from the bloodstream via degradation.

We first identified the cell surface peptidase by treating the cells at 4°C to inhibit receptor-mediated and fluid-phase endocytosis, which are alternative mechanisms by which cells could degrade ANP. We demonstrated that ANP was degraded by CPA47 cells under these conditions (fig. 1). The maximum rate of ANP degradation (Vmax) was found to be 35 pmol/10 min/10^5 cells, and the concentration of ANP that yielded one half the maximal rate of ANP degradation (Km) was found to be 325 nM. The enzyme was specific for degradation of ANP and some vasoactive peptides. However, not all peptides could block ANP degradation (fig. 2).

Conclusions from these studies include the following:

- CPA47 cells possess an enzyme on their cell surface that degrades ANP *in vitro*.
- The cell surface peptidase is specific for ANP and some vasoactive peptides.

By characterizing the biochemical process of how this and other peptidases degrade ANP, it may be possible to regulate ANP concentrations in plasma and, thus, manipulate some of the physiologic effects of this important fluid-regulating hormone.

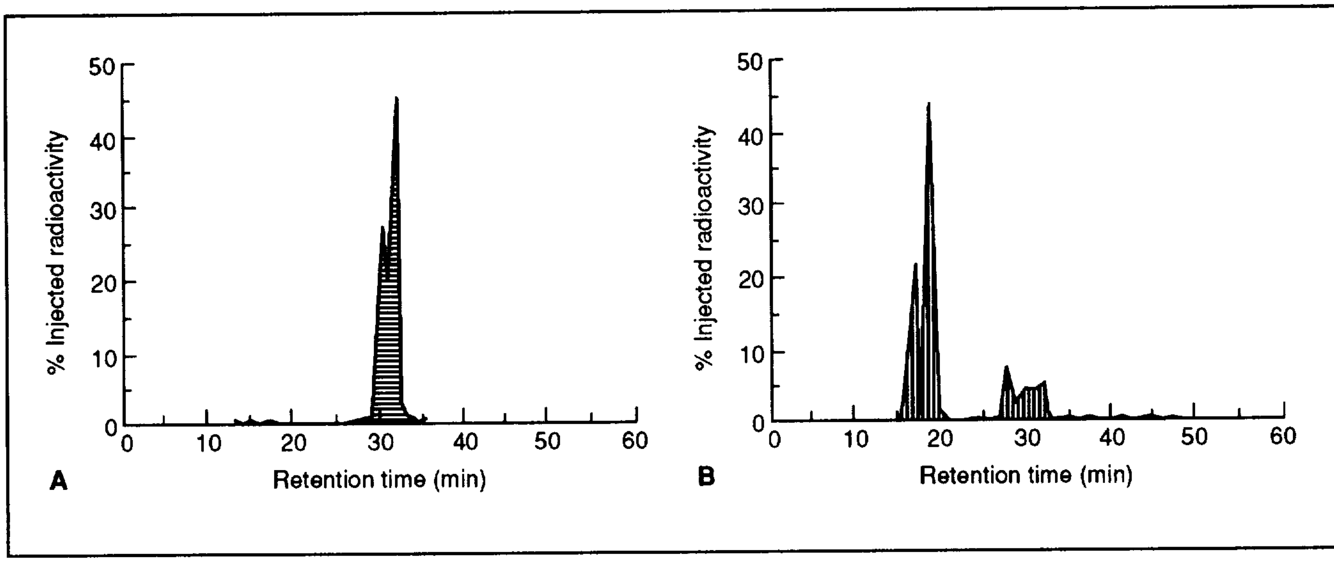


Figure 1 High-pressure liquid chromatography (HPLC) analysis of ANP degradation: CPA47 cells were incubated with 36 pM ^{125}I-ANP at 4°C for 4 hr. After incubation, the medium was collected and the samples were analyzed by HPLC. *Panel A.* ANP incubated with binding medium alone (intact ANP). *Panel B.* ANP incubated with binding medium with CPA47 cells. Intact ANP that elutes between 30-33 min was >85% lost after incubation with CPA47 cells.

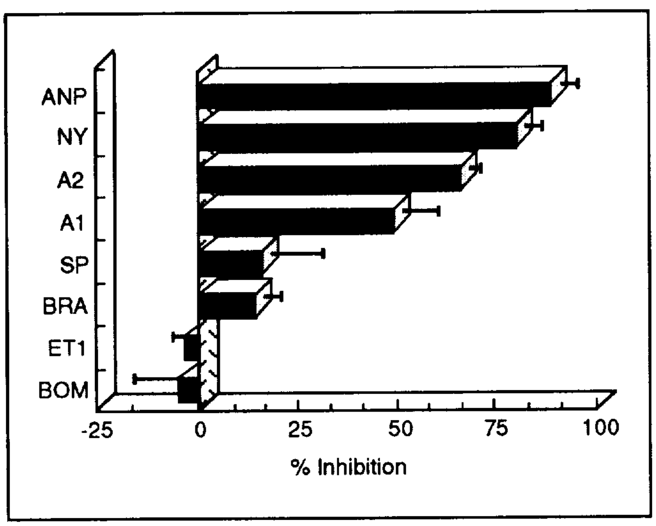


Figure 2 Specificity of CPA47 cell surface peptidase for ANP. Various biologically active peptides were incubated with radiolabeled ANP at 4°C to determine whether peptides other than ANP could inhibit degradation of radiolabeled ANP. The degraded ANP in the medium was determined by Sep-Pak analysis, which quickly separates degraded ANP from intact ANP. Each bar represents the mean and sample standard deviation of three independent experiments. SP, substance P; NY, neuropeptide Y; BRA, bradykinin; BOM, bombesin; A2, angiotensin II; A1; angiotensin I; and Et-1, endothelin 1. The results demonstrate that NY, A1, and A2 can significantly inhibit ANP degradation. Thus, these peptides may be degraded by the cell surface peptidase.

Blood Volume Responses of Men and Women During 13 Days of Bed Rest

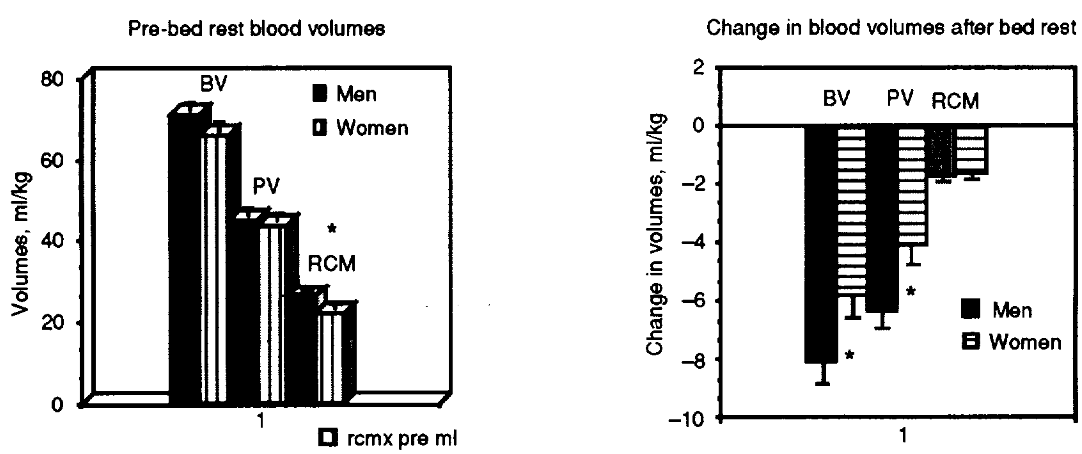
PI: **Suzanne M. Fortney, Ph.D./SD5**
Reference: **LS 9**

Changes in blood volume are thought to contribute to loss of orthostatic function and exercise capacity during spaceflight. The purpose of this study was to compare the loss of blood volume and its components (plasma and red cell mass) in healthy men and women during a 13-day simulated spaceflight.

Spaceflight was simulated by placing each subject in a 6-degree head-down position for 13 days. Food, fluid, and salt intakes were maintained at a constant level, similar to levels consumed on Shuttle missions (2500 kcal/day, 2500 mL/day, and 4 g/day, respectively). Ten women (33.3 ± 6.0 years) with a history of normal menstrual function, who were not taking oral contraceptives, and 10 men (31.5 ± 5.2 years, mean and SD) completed 2 days of ambulatory control and 13 days of bed rest. Blood volume measurements were obtained on each subject on the first ambulatory pre-bed rest day and on the last bed rest day. Plasma volume (PV) was measured by the dilution of 2 microcuries of ^{125}I-labelled human serum albumin. Red cell mass (RCM) was measured by the dilution of 40 microcuries of ^{51}chromate-tagged, autologous red blood cells. Blood volume was calculated as the sum of the PV and RCM. All values were divided by a subject's body weight to normalize for differences in body size.

Prior to bed rest, the women had significantly smaller RCM, but similar PV and BV. During bed rest, both men and women had significant decreases ($P < 0.01$) in PV and RCM. The PV decrease in the women (4.1 ± 0.6 mL/kg) was significantly less ($P < 0.05$) than the PV loss in the men (6.3 ± 0.6 mL/kg). The decreases in RCM were similar.

These results suggest that hormones associated with normal menstrual function may act to help retain PV in women during simulated spaceflight.



*The corresponding value is significantly different between the men and the women.

Figure 1.

Cardiovascular Monitoring of Space Shuttle Astronauts During Return to Earth

TM:	**J. B. Charles, Ph.D./SD5**
PI:	**M. M. Jones/KRUG**
	K. A. Fuhrmann/KRUG
Reference:	**LS 10**

Orthostatic function refers to the various mechanisms by which the cardiovascular system maintains adequate blood flow to the brain during and after changes in body position. In a gravitational environment, the orthostatic stress of standing is accompanied by fast-acting reflexes that maintain brain blood flow. However, the redistribution and loss of body fluids and other complex changes that occur in weightlessness can compromise orthostatic function to the extent that presyncopal symptoms or syncope (fainting) may occur upon standing. In fact, since the resumption of Shuttle flights in 1988, postflight orthostatic instability has been observed in 15 to 20% of crewmembers, even though those crewmembers used a saline fluid-loading countermeasure before landing. Orthostatic instability could become life threatening if an emergency egress from the Orbiter were necessary.

The objectives of this project were (1) to develop hardware to document the orthostatic function of crewmembers during the actual stresses of entry, landing, seat egress (standing for the first time after landing), and Orbiter egress; and (2) to use this hardware to assess the effectiveness of proposed countermeasures to orthostatic intolerance.

Crewmembers wear a pressure suit that also has g-suit capabilities during launch and entry to protect themselves in the event of the loss of cabin pressure or bailout. These launch and entry suits (LESs) were modified to provide a pass-through for instrumentation. A bioinstrumentation port (BIP), which allows cables up to 3/8 in. in diameter to pass through the suit, was added to the LES between pressure bladders on the right thigh. The BIP provides cable access while maintaining the air-tight integrity of the LES.

Because the crewmembers were to be monitored not only during entry and landing but also during Orbiter egress, the hardware had to be portable, battery powered, and small enough to fit in a pocket that was added to the LES over the BIP. Because space and development time were limited, it was decided that only electrocardiogram (ECG), blood pressure (BP), posture, and acceleration would be monitored. The following hardware was selected:

- Automatic Blood Pressure Monitor (ABPM) [Suntech Model Accutracker II]

  This commercial ambulatory BP monitor uses an R-wave-gated auscultatory technique to determine discrete BPs and heart rates at pre-set intervals. It was modified to provide continuous analog outputs of ECG, BP cuff pressure, and Korotkoff sounds. The monitor was shielded against electromagnetic interference by installing ferrite beads on the inputs and wrapping the device with aluminum tape. It is powered by four AA batteries.

- Single-Axis Accelerometer [Endevco Model 7290-10]

  These accelerometers are small, durable, and provide 0.2 V/g analog output. Three such accelerometers are mounted on the ABPM on the thigh to provide X-, Y-, and Z-axis acceleration of the crewmember during entry. A fourth accelerometer is mounted on the torso; when compared to the thigh accelerometers, it provides postural information. The accelerometer assembly is powered by four 9V batteries.

- Cassette Data Recorder [TEAC Model HR-40G]

  Nine channels of analog data and voice can be recorded on a magnetic cassette for up to 3 hours using this recorder, which is powered by one 9V battery. Voice and analog signals from the ABPM and accelerometers are recorded here.

To use the equipment, a crewmember applies three ECG electrodes to the chest and a K-sound microphone and BP cuff over the brachial artery on the upper arm. The cable from the crewmember attaches under the LES to a cable potted in a plug, which fits in the BIP. The BIP plug cable connects to monitoring hardware outside the LES. The ABPM, recorder, and three accelerometers are placed in a 6.5-by-8.5-by-2 in. pouch and stowed in a pocket on the right thigh. A voice microphone and torso accelerometer extend out of the pocket and attach to the LES near the neck ring.

The hardware was off-gassed, tested for electromagnetic interference, and evaluated for inflammability. To assure it would not hinder mobility during scheduled activities or emergency egress, it was evaluated by crewmembers during egress and bailout simulations. In addition, the integrated package was validated during brief weightlessness on the NASA KC-135 aircraft.

This equipment configuration has been used successfully by 18 crewmembers on 8 Shuttle flights. Preliminary findings are that heart rate increases and blood pressure decreases more upon seat egress than at any other time during the entry, landing, and egress sequence. In fact, some individuals have exhibited near-maximal heart rate responses, even after short (4 to 5 day) flights.

The ECG, BP, posture, and acceleration can be monitored on Space Shuttle astronauts during entry, landing, and egress using the portable hardware configuration described in this paper. Findings indicate that orthostatic function retains very little reserve capacity immediately after landing. The capability of performing strenuous egress activities in an emergency is not assured.

The authors will continue to investigate the cardiovascular responses to entry, landing, and egress to understand the influence of factors such as flight duration, hydration status, in-flight and preflight exercise history, space motion sickness severity, etc. Such an understanding is necessary before recommendations for additional countermeasures to combat orthostatic intolerance can be made.

Noninvasive Cardiovascular Monitoring on Routine Space Shuttle Flights

TM:	**J. B. Charles, Ph.D./SD5**
PI:	**M. M. Jones/KRUG**
	M. A. Bowman/KRUG
	M. W. Bungo, M.D./SD5
Reference:	**LS 11**

The development of countermeasures to the negative consequences of cardiovascular adjustments to spaceflight factors requires detailed, accurate measurements of those effects. However, such cardiovascular monitoring is much more difficult to accomplish in the weightless environment of the Space Shuttle than it is on Earth. There are many constraints on hardware: volume, weight, inflammability, power requirements, electromagnetic interference and compatibility, and ease of use are but a few considerations. In the majority of cases, the techniques are also noninvasive to avoid medical complications and to increase acceptance among volunteer astronauts.

The Cardiovascular Laboratory at NASA/ Johnson Space Center is the developer, sponsor, and/or user of a number of cardiovascular measurement capabilities on the Space Shuttle. Given the "operational" nature of the laboratory research, the equipment described here is intended for use in the living quarters, or "middeck," of the Space Shuttle Orbiter on routine flights, as well as in the laboratory module that is carried on selected Spacelab missions. A separate inventory of similar equipment has been developed for use specifically in the Spacelab module and will not be reviewed here.

The following parameters can currently be measured during routine Space Shuttle missions, when circumstances permit.

The electrocardiogram (ECG) is perhaps the most common cardiovascular measurement made in spaceflight, for it is used in operational monitoring and in research. The ECG can be monitored in several ways on board the Orbiter. The operational bioinstrumentation system (OBS) is flown on each Shuttle mission for monitoring during spacewalks or in case of an emergency that requires ECG monitoring, but it may also be used for research. The OBS provides a one-lead ECG signal that can be telemetered to Earth at 100 Hz. Two crewmembers can be monitored simultaneously with this system.

A clinical Holter monitor [Spacelabs Model 90205] has been used on nine Shuttle flights. This monitor records two leads of ECG onto a tape for up to 24 hours. Other pieces of equipment (i.e., blood pressure monitor and echocardiograph) also have ECG capabilities.

Blood pressure can be measured manually, with a blood pressure cuff and stethoscope carried as standard equipment on each Shuttle mission; a dedicated cuff and stethoscope can also be included in the hardware for specific investigations. However, automated devices are routinely used for research to make more efficient use of the astronaut's time and to improve data quality.

The automatic blood pressure monitor (ABPM) [Suntech Accutracker II] is a clinical ambulatory monitor, capable of recording blood pressure and heart rate values at set intervals for up to 24 hours. It uses an R-wave-gated auscultatory technique to determine blood pressure. In addition to storing digital values, the ABPM can generate ECG and blood pressure waveforms to be recorded to tape. The ABPM has been used on nine Shuttle flights.

Cardiac dimensions and function can be measured in flight with echocardiography (cardiac ultrasound imaging). An echocardiograph [ATL 4000 S/LC] has been modified and repackaged to fit in a Space Shuttle middeck locker and to operate on Orbiter power (115 Vac, 400 Hz, 3 phase). It has made 2-dimensional images and M-mode measurements on three Shuttle missions. It will be replaced in 1992 by another echocardiograph with Doppler capabilities, a modified version of the commercially available Biosound Genesis II. Data are recorded on the Shuttle video recorder or on a dedicated 8-mm camcorder.

Cerebral blood flow has been assessed on three Shuttle flights using a transcranial Doppler device [Eden Medizinische Elektronik Model TC2-64B] to measure middle cerebral artery blood flow velocity. This commercial device was modified to fit in a Shuttle middeck locker and to operate on 28 Vdc Orbiter power. Data from it are recorded to magnetic tape.

A system for noninvasive estimation of central venous pressure (CVP) has been flown three times on the Shuttle. It is based on the method of Durr, which equates CVP with the increase in intrathoracic pressure that briefly interrupts jugular vein blood flow. Jugular flow is monitored with a small Doppler device; intrathoracic pressure is measured with a mouthpiece transducer. Doppler and mouthpiece pressure data are recorded on magnetic tape.

Fluid shifts can be estimated by tracking changes in leg volume. A stocking plethysmograph consists of a slightly elastic stocking with fixed longitudinal locations for circumferential tapes that are marked with colored pens through aluminum windows. A different color is used during each measurement session. Leg circumferences are determined from the tape marks postflight, and leg volumes are calculated from the segmental circumferences. This device has flown on five Shuttle flights.

All of the above parameters can be measured in stand-alone investigations, but they can also be combined to monitor crewmembers during various stresses. Special areas of interest to cardiovascular monitoring include

- Launch
- Entry
- Extravehicular activity (spacewalks)
- Lower body negative pressure
- Exercise using the Shuttle treadmill (or, in the near future, the cycle ergometer).

A significant collection of instrumentation is available for use on board the Space Shuttle. When integrated into well-planned investigations, the capability exists for a "middeck cardiovascular laboratory" of surprising flexibility—which is comparable to a modern, well-equipped laboratory on Earth.

This work was supported by NASA contract NAS9-18492.

Electronic Vision-Occlusion Goggles for Performing Visual-Vestibular Integration Experiments

TM: Millard F. Reschke, Ph.D./SD5
PI: Mike Zerkus/KRUG
Jacob J. Bloomberg, Ph.D./SD5
William P. Huebner, Ph.D./SD5
Deborah L. Harm, Ph.D./SD5
William H. Paloski, Ph.D./KRUG

Reference: LS 12

The vestibuloocular reflex (VOR) serves to stabilize gaze against head movement, ensuring that a stable retinal image is maintained. It has been previously demonstrated that exposure to microgravity produces changes in the VOR (Vieville et al., 1986) and in eye-head coordination (Thornton et al., 1988). Alterations in the VOR can result in an unstable visual scene and illusions of self and/or surround motion associated with head movements. These effects may increase in magnitude as mission length increases.

Current vestibular experiments are designed to examine the effects of spaceflight on gaze control on orbit, during reentry, and after landing. Technical limitations of previous in-flight equipment have precluded the use of an important test of VOR function that involves the recording of eye and head movements during brief periods of occluded vision. The ability to perform this experimental paradigm during different phases of the mission would provide information necessary for the development of countermeasures against possible visual-vestibular changes associated with extended duration missions.

Electronic vision occluding goggles (EVOGs) (fig. 1) have been developed for performing this and other vestibular experiments on the Shuttle middeck, both in flight and during reentry. The EVOGs selectively permit or occlude vision through either manual or automatic control. Biaxial rate sensors housed in the goggle frame transduce head rate in the pitch and yaw planes. Electrooculography (EOG) amplifiers and lead wires for measuring eye movements in the vertical and horizontal planes are also included with the assembly. A small laser is mounted on the goggle frame for head alignment tasks.

The EVOGs consist of a lightweight frame that is custom fit to the head. Ear pieces, a nose piece, and a Velcro strap secure the EVOGs to the face and provide alignment.

The EVOG lens is made of polymer dispersed liquid crystal (PDLC). A PDLC is a flexible material similar to the liquid crystal displays of hand-held calculators. Normally, PDLC material is opaque. A unique, transformerless drive circuit was developed to provide 30 V RMS ac to the lens, causing the lens to clear.

The drive circuit allows for manual or automatic control of lens function. Included in this circuitry is a timer, operated by a remote control push button that provides a random delay between 0.25 and 2.0 seconds before vision is occluded. The goggles remain opaque for 2.0 seconds, then automatically clear. This feature provides the brief period of vision occlusion necessary to measure the VOR during high-frequency, low-amplitude head movements.

The head rate sensors, EOG amplifiers, and small laser are off-the-shelf items that were modified for use in the EVOG assembly.

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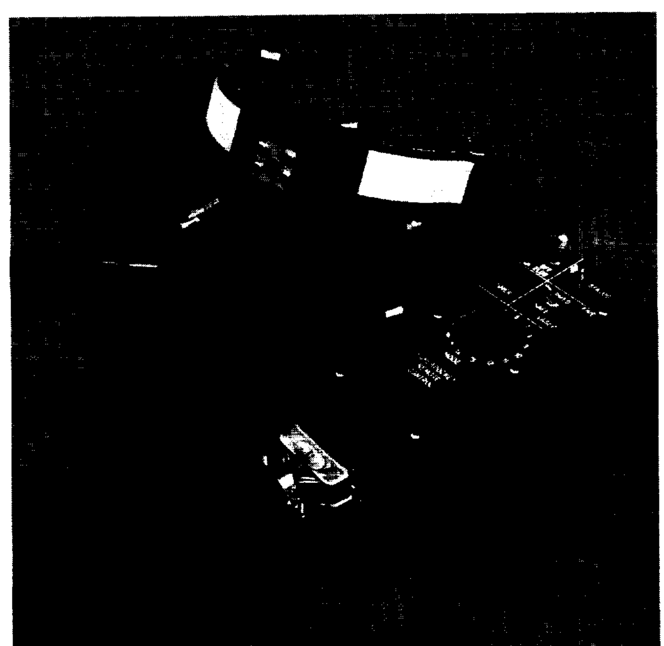

Figure 1. Electronic vision occluding goggles.

Stress-Assisted Nucleation: Its Role in the Etiology of Decompression Sickness in Microgravity

TM: **Michael R. Powell, Ph.D./SD5**
PI: **James Waligora/SD5**
William Norfleet, M.D./SD5
Mark Davis/SD5
Reference: **LS 13**

Astronauts report a lower incidence (current reports indicate 0%) of decompression sickness (DCS) during extravehicular activity (EVA) than would be predicted (25% expected) from studies performed in ground-based laboratories. It is hypothesized that the differences can be traced to a reduction in stress-assisted nucleation (the abaroferric hypothesis). The degree of whole-body gas phase formation will be lower in simulated microgravity, and this can be determined noninvasively by means of the Doppler ultrasound bubble detector.

Joint-pain decompression sickness ("the bends") occurs as the result of the formation of a gas phase in connective tissue of movable joints. Astronauts appear to have this reduced risk of DCS following at least 3 days in microgravity. This would be compared to human experimental subjects from ground-based tests in unit gravity who have normally ambulated for at least 3 days. Curiously, astronauts might even be expected to experience a greater degree of gas phase formation (and DCS) because of ionizing radiation and its effects on the promotion of phase transitions, as seen in gas-liquid bubble chambers.

To date, U.S. astronauts have performed 30 manned EVAs, and reported no incidences of even mild decompression sickness. Several explanations have been proposed; they are (1) unawareness of any prolem of joint soreness while intensely involved in EVA activities, (2) a statistically allowed "cluster phenomenon" of safe, DCS-free decompressions, (3) repetitive decompressions by a set of individuals apparently less susceptible to decompression sickness, (4) modification of ventilation-perfusion ratios in microgravity, (5) cardio-vascular changes (e.g., fluid shifts) resulting in an increased rate of inert gas washout, (6) changes in the hormone system, or a decrease of the immunologic response (e.g., complement factor C5a), or (7) a lack of tissue micronucleating agents and/or mechanism(s) for the growth of a tissue gas phase. A test of the last hypothesis has been called PROJECT ARGO; it has several aspects.

An analysis of data reported in the literature indicates a prevalence of DCS in the lower extremities. Similarly, studies conducted at the NASA/Johnson Space Center show a prevalence of problems in the lower extremities. Our results of PROJECT ARGO indicate that a lower incidence of tissue gas-phase formation occurs in bed-rested individuals (that is, hypokinetic and not subjected to gravitational stress). This is a crossover experimental design wherein 20 individuals will be decompressed after being either bed rested or ambulatory. To date, 10 individuals have crossed over in the study, and the results illustrate that bed rest confers DCS protection, presumably from a reduction in the mechanisms of stress-assisted nucleation and its ability to produce tissue gas micronuclei. Paired differences indicate that the Doppler grade of bed rested versus Doppler grade ambulatory is negative for all time periods.

The effect of pulmonary gas embolism on gas exchange (oxygen and carbon dioxide) is being measured. Results do not give an indication that circulating microbubbles increase pulmonary dead space.

ECG measurements have been made to investigate perturbations of myocardial function, but no such perturbations have been found. These were postulated to possibly occur from elevations of pulmonary capillary resistance.

An interrogation of the arterial circulatory system of the brain is being performed by means of transcranial Doppler ultrasonography. Of the subjects monitored to date, six displayed a Spencer precordial grade of III or IV and one of these had Doppler-detectable gas bubbles in the middle cerebral artery. That individual also sustained a DCS incident involving the (peripheral) nervous system.

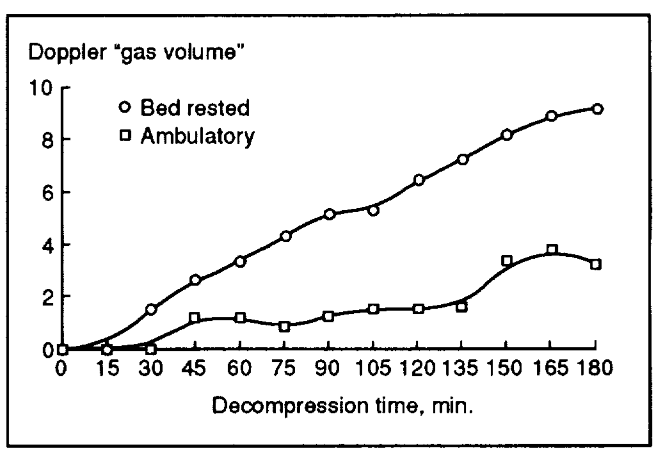

Figure 1. Decompression stress in ambulatory versus hypokinetic individuals.

A Statistical Model Describing the Incidence of Decompression Sickness and Doppler-Detectable Gas Bubbles During Altitude Decompression

TM: **James M. Waligora/SD5**

PI: **David J. Horrigan, Jr./SD5**
John H. Gilbert, Ph.D./SD5
Johnny Conkin/SD5
John Stanford, Jr./KRUG
Benjamin F. Edwards, Jr., Ph.D./SD5

Reference: **LS 14**

For several years, NASA has had an extensive program of testing various prebreathe methods with 100% oxygen (O_2) prior to exposure to a decompression for extravehicular activity. Currently, almost 1000 test-subject exposures to altitude have been performed at the Johnson Space Center and under NASA contract at Brooks Air Force Base, San Antonio, Texas. These studies have been designed to determine the efficacy of different O_2 prebreathe procedures, and the results have been treated by means of statistical analysis that relates the amount of nitrogen (N_2) in certain body tissues (or "compartments") and the rate of occurrence of both Doppler-detectable gas bubbles (sometimes termed venous gas emboli) and altitude decompression sickness (DCS).

To date, 36 different DCS prevention procedures have been performed. The environmental variables have included the maximum test altitude, O_2 prebreathe duration, decompression staging techniques, final breathing gas mixture, and exercise level both before and during decompression.

A measure of decompression stress, or "tissue ratio" (TR), relates the partial pressure of nitrogen dissolved in (specific) "compartments" to the ambient pressure; this allows comparison between test subjects' responses independent of environmental parameter alterations. The final amount of N_2 dissolved in the tissues of the body is dependent upon the partial pressure of N_2 in the prebreathe mixture, the blood perfusion rates, and the N_2 solubility in the various tissues within the body. The N_2 "compartment" half-time of 360 minutes was determined by statistical methods as corresponding to the inert gas washout rate that best described the incidence of Doppler-detectable gas bubbles (in the pulmonary artery) and DCS for all of the various exposure parameters.

Data derived from these ground-based studies have been analyzed to determine the relationship between incidence of decompression sickness, its severity, and of circulating microbubbles to the tissue ratio. The prevention methodology has emphasized whole body denitrogenation by means of prebreathing 100% oxygen.

Starting with calculated nitrogen loads in the experimentally derived critical "compartment," whose washout half-time is 360 minutes, nonlinear regression curves were fitted to the approximately 1000 tests describing the incidence of gas bubbles in the pulmonary artery (confluence of the venous return) and of joint pain DCS (commonly referred to as "the bends"). An additional curve concerned the termination date of a test or showed delayed onset of symptoms. One boundary condition was that as the TR of a subject approached that encountered at sea level, the incidence of Doppler-detectable gas bubbles and DCS decreased to zero; the incidence of gas bubbles was much more common than DCS. In all cases but two, bubbles were found to be a necessary, but not a sufficient, condition for the subsequent onset of DCS symptoms.

The original model utilized by Conkin, et al. (1987) utilized Hill's equation in the form

$$p = \frac{(TR_x - 0.78)^n}{(TR_x - 0.78)^n + (TR_{50} - 0.78)^n}$$

where p is the probability of a positive response (DCS), TR is the tissue ratio in the 360-minute tissue, and n is the fitting constant.

This has been recently modified with the assistance of C. R. Hallum, Ph.D., using the following logistic regression model that better describes the data:

$$p = \frac{\exp\{a + n \ln [TR_{360} - 0.78]\}}{1 + \exp\{a + b \ln [TR_{360} - 0.78]\}}$$

where a,b are constants.

The equation describes a correlation between the physiological events of gas bubble formation and DCS symptoms and the (mathematically derived])TR at various altitudes [ambient barometric pressures]. For any given TR, these formulae and curves describe the probability (rather than specifically predict) of an incidence of DCS in a group of individuals.

The Application of Integrated Knowledge-Based Systems for the Biomedical Risk Assessment Intelligent Network

TM: Gerald R. Taylor, Ph.D./SD5

PI: Karin C. Loftin, Ph.D./KRUG
Bebe Ly/PT4
Laurie Webster/ER2
James Verlander, Ph.D./SD5
Gerald R. Taylor, Ph.D./SD5
Gary Riley/PT4
Chris Culbert/PT4
Tina Holden, Ph.D./SP3
Marianne Rudisill, Ph.D./SP3

Reference: LS 15

A primary goal of NASA for spaceflight is to maintain acceptable levels of health, safety, and performance of the crew. To achieve this goal, medical teams have monitored the health of the crew preflight, in flight, and postflight throughout the history of manned space programs. During the Skylab missions, in-flight biomedical data were used as a basis for making decisions about the flight duration of successive Skylab missions. For extended tours of duty on Space Station Freedom and lunar/Mars stations, a great effort will be required to monitor the crew and to administer appropriate countermeasures to prevent in-flight biomedical problems.

Determining the risk of in-flight biomedical problems is a major step toward preventing them. It is crucial to make an assessment quickly and initiate countermeasures. It also is important to predict the impact of the selected countermeasures on crew health, safety, and performance and to evaluate each countermeasure relative to its impact on others.

A solution to the decision-making process required for long-duration flights is the application of integrated knowledge-based systems or expert systems. They reduce the volume of data, facilitate data interpretation, and resolve incompatible data that are necessary for timely risk assessment. To this end, NASA is supporting the development of the Biomedical Risk Assessment Intelligent Network (BRAIN), which is an integrated network of multiple expert systems that provides a composite analysis to the user. The authors hypothesize that BRAIN will reduce the time required to arrive at real-time decisions about biomedical risk analysis and management.

The BRAIN concept is illustrated as a triangle (fig. 1) with users on the left side and expert systems on the right side. The network still permits each system to work independently with the mission manager or other users. Through BRAIN, each system may access pertinent data from other systems. BRAIN cooperates with the independent expert systems by use of a knowledge base that relates all of them.

The functions of BRAIN are to

- Access the Infectious Disease Risk Assessment (IDRA) prototype, the Exercise Countermeasures Intelligent System (ExerCISys), the Performance Prediction Model, and other undefined, separate expert systems for pertinent information.
- Assess a composite biomedical risk and recommend countermeasures to the user.
- Function as a clearing house of information to be shared among systems.
- Resolve incompatible information given by other expert systems and to derive a composite recommendation for a mission manager.

This report describes the joint effort among various NASA elements to test the feasibility of integrating two independent knowledge-based systems, the IDRA prototype and ExerCISys, as a model of BRAIN. Implementation of this effort addresses the technological aspects of: (1) knowledge acquisition, (2) integration of IDRA components, (3) use of expert systems to automate the biomedical prediction process, (4) development of a user-friendly interface, and (5) integration of IDRA and ExerCISys prototypes. Because the C Language Integrated Production System (CLIPS) and the X-Window System were portable and easily integrated, they were chosen as the tools for the initial IDRA prototype.

The prevention of infections during manned spaceflights is important and is related to exercise, a vital countermeasure to prevent cardiovascular deconditioning of humans in space. Because the epidemiology of and procedures for preventing, diagnosing, and treating influenza were well defined, the IDRA prototype was developed initially to assess the probability of influenza infection. During its early development, the integrated knowledge base relating infection and exercise resides in the IDRA prototype. This also provides an opportunity to evaluate the type of information that will be shared, as well as what will remain private between the systems. When the requirements for BRAIN are better defined and implemented, its integrated knowledge base will be moved to a separate hardware and software environment, and all systems will be connected to BRAIN through a network.

The knowledge for the IDRA knowledge base was extracted and analyzed from textbooks and journal articles. The critical indicators that predict the probability (risk) of influenza were identified. The risk of influenza for an individual is described by general population statistics—it depends on an individual's age group, location, and level of immunity. This information is encoded in a set of rules using CLIPS. A subset of these rules incorporates the effect of exercise on the risk of infections. Once the communications between the IDRA prototype and the ExerCISys prototype are linked, IDRA will query ExerCISys for the level of exercise and the level of fitness based on aerobic capacity that was achieved by each subject. This information will execute additional rules by IDRA that generate a risk assessment of influenza.

Figure 2 illustrates the major components of the IDRA prototype. A C-based data manager interacts with all the components of the system. It processes information from the data base and from the user interface. The expert system using CLIPS assesses the probability of influenza—it retrieves the information from the data manager and outputs it to the user interface. The probability of infection and illness is displayed in the form of text and graph. All tools are portable and compatible with Space Station Freedom requirements. Preliminary results suggest that an integrated IDRA prototype is feasible and can serve as a model to develop BRAIN.

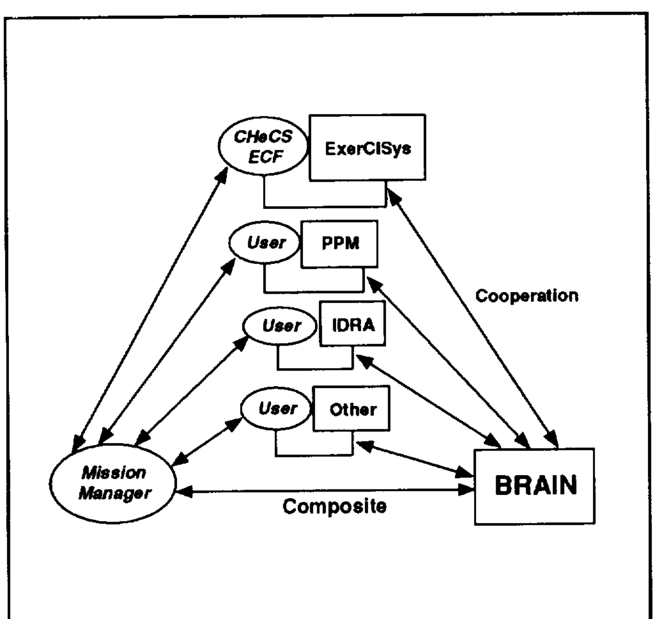

Figure 1. The BRAIN concept.

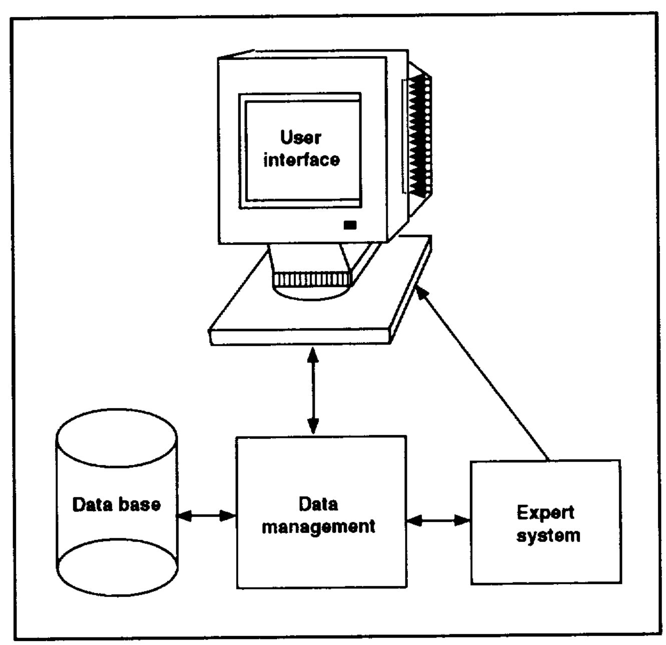

Figure 2. Major components of the IDRA prototype.

Concept Development of Preflight Blood Volume Reduction as a Countermeasure to Fluid Shifts in Spaceflight

TM: John B. Charles, Ph.D./SD5
PI: Karl E. Simanonok, Ph.D./NRC
R. Srini Srinivasan, Ph.D./KRUG
Reference: LS 16

The mechanisms causing an increased excretion of water and electrolytes in ground-based experiments simulating weightlessness by water immersion or head-down tilt (HDT) are thought to be initiated by a headward redistribution of body fluids. In weightlessness, circulatory changes include an early and rapid in-flight elevation of hemoglobin concentration coinciding with a loss of body mass that reflects a negative water balance. Most of the water loss occurs within the first 3 days, and a plateau is thought to be reached by 10 or 20 days of weightlessness. Red cell mass may decrease by 15% after 2 or 3 weeks in space.

Reduction of blood volume in weightlessness is considered to be an adaptation to the space environment. Unfortunately, this leaves astronauts maladapted to gravity when they return to Earth; postflight orthostatic intolerance has been a problem that is now partially counteracted by oral rehydration before reentry. It would be desirable to limit in-flight body fluid losses if possible. There is also a possibility that fluid shifts play a role in space sickness etiology. Reducing the physiologic effects of fluid shifts might therefore help to ameliorate the space sickness problem.

The concept under development is that preflight adaptation (preadaptation) of the circulation to a lower blood volume should decrease the central volume expansion due to fluid shifts in weightlessness and attenuate the circulatory, hormonal, and renal responses experimentally observed in water immersion and HDT that are often used to model weightlessness. The net effects should be an attenuation of the physiologic responses to fluid shifts and decreased body fluid losses.

In two short-term water immersion experiments in human subjects, the hypothesis was supported that some of the major physiologic effects of a fluid shift could be counteracted by reducing the blood volume prior to the fluid shift. Before embarking on bed rest studies of the countermeasure, we used a validated mathematical model of circulation, the Guyton Model of Fluid, Electrolyte, and Circulatory Regulation, to further test the countermeasure concept. The utility of mathematical modeling for our purposes is (1) to extend the time period for testing the preflight blood volume reduction countermeasure well beyond that possible in water immersion experiments, (2) to assist in the experimental design of further tests of the countermeasure using human subjects, and (3) to efficiently test different means of implementing the countermeasure.

We used computer simulation of 6° HDT to model fluid shifts. The starting volume of blood before simulated HDT was 5024 ml. After prolonged 6° HDT (70+ simulated days), the equilibrium blood volume was 4490 ml. The difference, 534 ml, or about 11% of the starting blood volume, was the preadaptation volume to remove before HDT to test the countermeasure.

The protective effects of preadapting the circulation to fluid shifts in maintaining blood volume, extracellular fluid volume, and total body water are shown in figures 1, 2, and 3, respectively. Data are plotted on a logarithmic time scale so that all phases of the experiment out to 70 days may be clearly distinguished. Of particular interest in figure 1 is that, after 10 hours of simulated HDT, the blood volume was slightly better maintained for 20 to 30 days by a prior bleeding. During the first few hours, the loss of fluid by elevated urine flow (fig. 4) in HDT, without the countermeasure, rapidly met and surpassed the initial fluid loss due to a prior blood volume reduction.

Simulation results show that preadaptation of the blood volume by a procedure resembling a blood donation immediately before head-down bed rest is beneficial in damping the physiologic responses to fluid shifts and reducing body fluid losses. In addition to attenuation of the volume losses, figures 1, 2, and 3 illustrate that the rates of change of the body fluid volumes during HDT are also decreased by prior blood volume reduction. Decreases in both the rates of change and the absolute magnitudes of the changes in body fluid volumes suggest that the physiologic stresses upon the simulated body were decreased. Fluid shifts disturb the internal environment, invoking homeostatic responses that act to return the parameters of the internal environment to their normal operating range. Preadaptation of the blood volume may, therefore, reduce the magnitude of the homeostatic stresses accompanying adaptation to weightlessness.

The most unambiguous potential benefit of the countermeasure is that postflight orthostatic tolerance might be improved by the enhanced fluid retention for missions up to 20 or 30 days in length. There may also be other benefits. Head congestion, facial edema, and headaches in astronauts might be lessened. More important, if it is true that fluid shifts in some manner contribute to space sickness etiology, then it is possible that preadaptation of the circulation may be beneficial in ameliorating space sickness by reducing the physiologic impact of fluid shifts. Unfortunately, the mechanisms causing space sickness are only speculative and there are no nausea or motion sickness variables in the Guyton Model.

It is important to consider other ramifications of blood volume reduction that may be relevant to astronauts. We are not proposing that the optimum method to preadapt the circulation to weightlessness is a procedure resembling a blood donation. This is because blood volume is usually restored within a day or two after an acute hemorrhage, although the restoration of plasma proteins and cells takes longer. Launch delays could easily ruin the effectiveness of that approach. A preflight regimen of diuretics, water immersion, or HDT might effectively reduce the blood volume; at least one astronaut has slept in HDT for approximately 10 days prior to each of his four Shuttle missions to reduce his blood volume and ameliorate the effects of fluid shifts. He reports that he suffered none of the head congestion, facial edema, or headaches that astronauts commonly experience in weightlessness, and he never became space sick.

Preflight orthostatic tolerance would, if anything, be decreased by blood volume reduction; so astronauts who were borderline in their orthostatic tolerance should probably not be preadapted unless their orthostatic tolerance could first be improved. Exercise capacity could be reduced somewhat by preflight blood volume reduction, and could conceivably affect an astronaut's performance in the event of a preflight emergency egress. These concerns must be thoroughly addressed before preflight blood volume reduction can be seriously considered for astronauts. Further computer simulations may be useful in answering some of these questions.

The utility of computer simulation in planning and designing experimental studies is amply demonstrated by this and previous simulation studies. Simulation is a highly cost-effective method for initial hypothesis testing and experimental design optimization, especially when investigating the physiology of human adaptation to weightlessness.

This computer simulation extends earlier work, which suggests that preflight blood volume reduction on the order of magnitude of an ordinary blood donation could be beneficial to astronauts by damping their physiologic responses to fluid shifts and reducing body fluid losses. These results suggest that this countermeasure to fluid shifts could possibly improve postflight orthostatic tolerance for missions as long as 20 to 30 days in duration, and could ameliorate some of the head congestion, facial edema, and headaches that afflict many astronauts. To the extent that fluid shifts contribute to the problem, an effective countermeasure to fluid shifts could also be beneficial against space sickness.

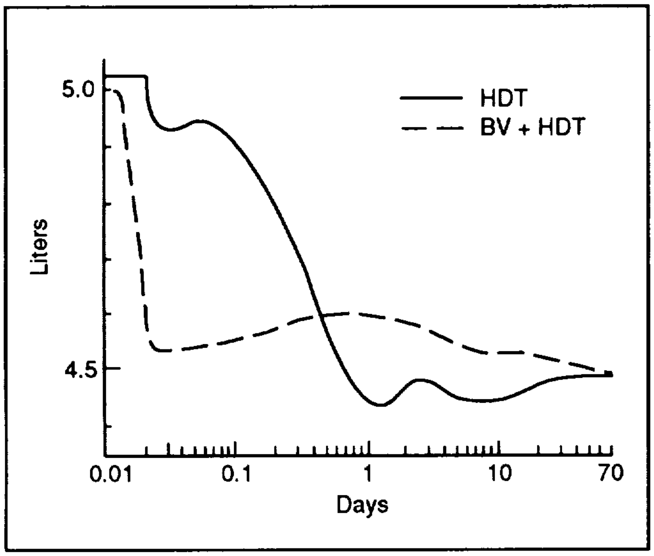

Figure 1. BV = blood volume reduction, acute reduction of blood volume by 534 ml in 18 minutes.

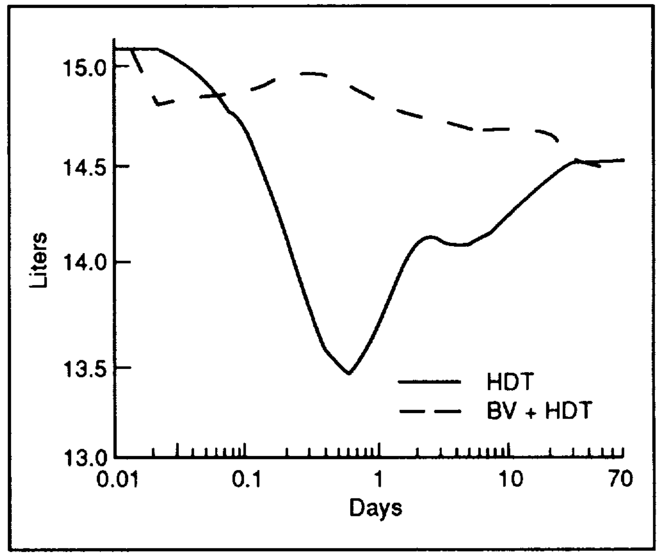

Figure 2. Extracellular fluid volume.

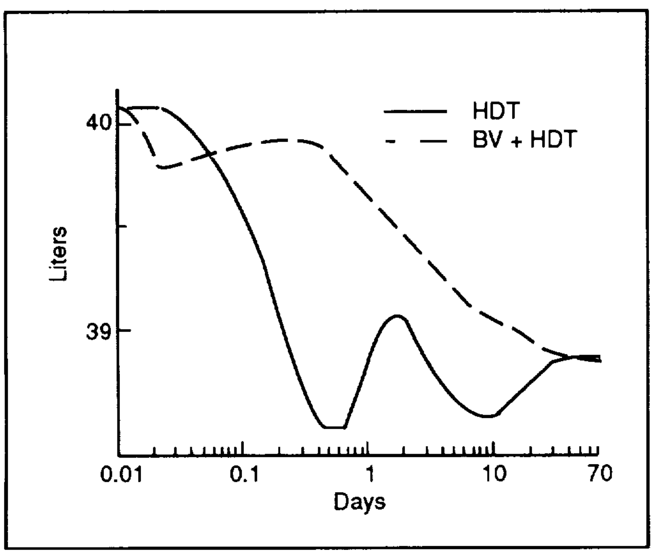

Figure 3. Total body water.

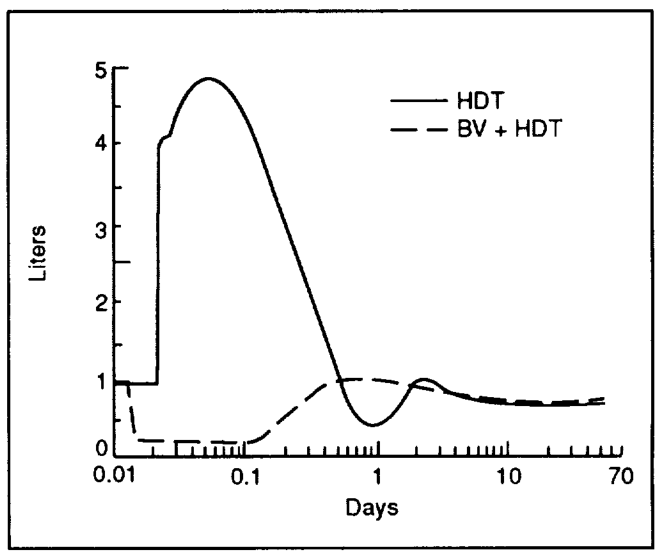

Figure 4. Urine flow.

Prediction of Space Sickness

TM:	**John B. Charles, Ph.D./SD5**
PI:	**Karl E. Simanonok, Ph.D./NRC**
	Edward C. Moseley, Ph.D./SD
Reference:	**LS 17**

Space sickness afflicts about two-thirds of Shuttle astronauts to varying degrees of severity. NASA has expended great effort in attempting to understand, predict, and treat space sickness because it is a nuisance and because mission performance can be negatively impacted in severe cases. An emergency Shuttle landing early in a mission could be endangered if the pilot and commander were space sick. Further, the potentially fatal risk of vomiting in a spacesuit necessitates an operational NASA policy prohibiting extravehicular activity (EVA) during the first 3 mission days. Most of the risk of space sickness during EVA is avoided by this policy because space sickness typically begins approximately 1 hour after orbital insertion, reaches a peak within 24 to 48 hours, and is usually resolved between 30 to 48 hours, although it can persist for 72 hours. The time course is variable, with occasional delayed-onset space sickness occurring after 2 days in space.

Preflight tests of astronauts' motion sickness susceptibilities do not correlate significantly with space sickness and are not useful for prediction. Yet, most experimental approaches to the space sickness problem thus far have focused on questions relating to neurovestibular adaptation to the unique environment of weightlessness. It may be more fruitful to regard novel neurovestibular responses to weightlessness as providing the primary nauseogenic stimulus, while other factors that accompany physiologic adaptation to weightlessness may change the threshold of susceptibility to nauseogenic stimuli in general. Among the insults upon homeostasis in the early hours and days of a mission that might lower an astronaut's tolerance to provocative vestibular stimuli are some of the effects of fluid shifts.

Immediately upon exposure to weightlessness, there is thought to be a dramatic headward fluid redistribution with substantial physiologic responses; space sickness follows closely upon the time course of these fluid shifts and the major physiological perturbations they produce. Fluid shifts caused by head-down tilt (HDT) in bed rest studies have been associated with dizziness and nausea upon head movement, spontaneous nystagmus, and vestibular illusions of tilting and falling. And water immersion has been reported to increase vestibular susceptibility to caloric stimulation so much that, in some subjects, the caloric stimulation had to be stopped. There are several potential physiologic mechanisms by which fluid shifts have been postulated to contribute to space sickness; for example, it has long been thought that elevated intracranial pressures may be involved in space sickness etiology.

We have examined the possibility that fluid shifts could contribute to the etiology of space sickness by using preflight variables relating to fluid, electrolyte, and cardiovascular status to successfully predict the incidence (not sick versus sick) and severity (none, mild, moderate, or severe) of space sickness. To date, we have identified nine such "fluid shift" variables, which are serum uric acid, red cell count, environmental temperature at the launch site (the blood volume varies with season and climate), serum phosphate, urine osmolality, serum thyroxine, sitting systolic blood pressure, calculated blood volume, and serum chloride (fig. 1). All nine variables were "forced" into the discriminant analyses so that they could be compared to each other in the prediction of both the incidence and severity of space sickness. These 9 variables were initially found to predict, with 80% success, space sickness incidence in a sample of 64 first-time Shuttle astronauts and to predict with 55% success space sickness severity using two methods of cross-validation on the original sample. For comparison, the percent success expected in predicting space sickness incidence by chance alone is 51%, and for space sickness severity is 32%. These results, if they hold up on further cross-validation, achieve a NASA technical goal set in 1982, which was the development of a risk profile for predicting the incidence of space sickness with 80% confidence.

In another analysis, a tenth input variable was added—hours spent in the Weightless Environment Training Facility (WETF), the large pool of water in which astronauts train in space suits for EVA. The WETF data by themselves suggested that WETF training may reduce space sickness severity (fig. 2, table I). This new added variable did not improve the prediction of space sickness incidence, but did improve the prediction of space sickness severity. In this analysis, the original nine fluid shift variables were entered without forcing them to be used in the discriminant analysis program. Eight of the variables were chosen (serum thyroxine was not) that correctly predicted space sickness severity, with 59% success by one method of cross-validation on the original sample and 67% success by another method. When WETF training time was added, prediction of space sickness severity was improved to 66% success by the first method of cross-validation on the original sample and to 71% by the second method.

The WETF training time may be another "fluid shift" variable because astronauts, while in WETF training, are not oriented by gravity, but remain physiologically susceptible to it — which causes cephalad shifts of fluid when they are head down. As a result, they may physiologically adapt to the fluid shifts, perhaps by reducing their blood volume, which also occurs in weightlessness. Alternatively, or in addition, WETF training could be protective against space sickness because of the visual adaptation that it may provide. In WETF training, astronauts can assume almost any orientation with the spacecraft mockups. This could help to accustom them to the novel visual orientations of the spacecraft experienced in space, thereby reducing their sensitivity to the "sensory conflict" that is presently the dominant paradigm of space sickness etiology.

Preliminary work has begun in substituting the analytical technique of logistic regression for discriminant analysis in the performance of these analyses. Logistic regression has improved the prediction of space sickness incidence to 87.5% success using the following five fluid shift variables: serum uric acid, red cell count, environmental temperature at the launch site, serum phosphate, and urine osmolality. Planned studies also include logistic regression on space sickness severity. The logistic regression model provides far simpler calculation of the prediction of new cases (i.e., astronauts who are first-time fliers) than does discriminant analysis. The capability of predicting space sickness incidence has, therefore, been provided to the NASA flight surgeons. The resulting success in the prediction of new cases of space sickness can therefore be determined prospectively.

Further retrospective studies are planned, however, as data (in addition to the data on the 64 first-time Shuttle astronauts) are in the process of being compiled. This will allow for retrospective true cross-validation studies, and it is expected that the increase in sample size will improve the strengths of prediction attainable by predictive methods.

There are a variety of methods of data transformation that may be performed to improve the strengths of predictions, and only a very few such transformations have been attempted so far. Therefore, we expect to also incrementally improve the strengths of predictions in future studies by such methods. We cannot ascertain that the variables found so far represent the optimum variables for space sickness prediction. Astronaut practices and procedures that may have been modified since our data from 64 astronauts were obtained may make the logistic model predictions invalid for astronauts flying today. Therefore, the variables of the predictive models we create will be continually scrutinized for their continuing usefulness, and new variables will be added to replace or augment those used to date. Perhaps the most fruitful outcome of this predictive modeling would be if some variables that emerge as significant predictors prove to be indicators of the physiologic mechanisms causing space sickness. If so, an understanding of underlying mechanisms could lead to development of nonpharmacologic countermeasures to one day alleviate the space sickness problem.

TABLE I. OBSERVED VERSUS EXPECTED (DUE TO CHANCE) FREQUENCIES OF SPACE SICKNESS IN ASTRONAUTS WITH AND WITHOUT WETF TRAINING

Observed frequency			
Score	WETF		
	Yes	No	Total
None	16	11	27
Mild	15	14	19
Mod+Sev	5	13	18
Total	36	28	64

Expected values			
Score	WETF		
	Yes	No	Total
None	15.2	11.8	27.0
Mild	10.7	8.3	19.0
Mod+Sev*	10.1	7.9	18.0
Total	36.0	28.0	64.0

Statistic	Value	D.F.	Prob.
Pearson chi-square	10.006	2	0.0067
Likelihood-ratio chi-square	10.394	2	0.0055

*The moderate and severe groups were combined to provide expected values in all cells greater than 5 for the chi-square tests presented below.

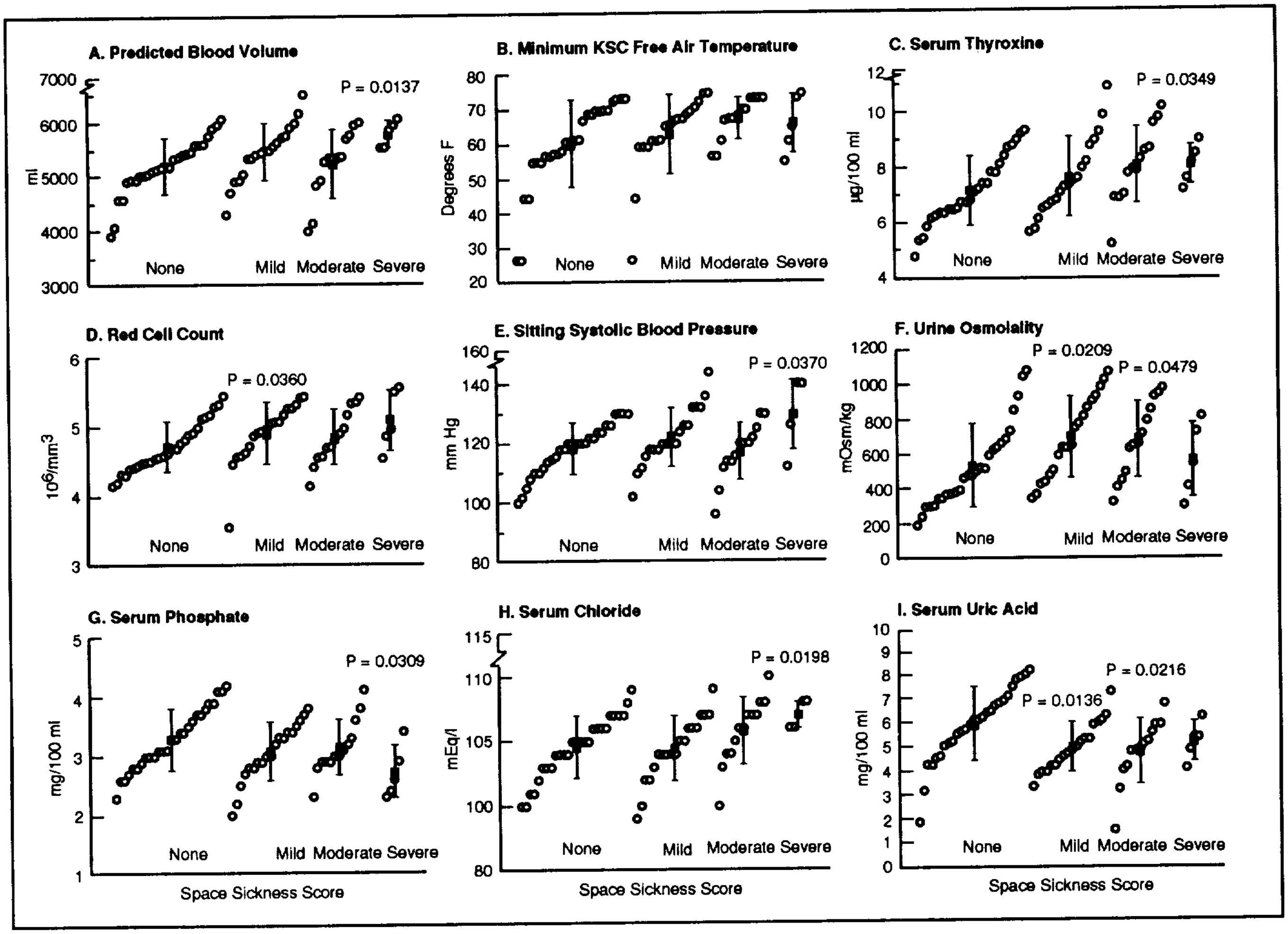

Figure 1. Nine preflight variables used to predict space sickness. Individual points are plotted in ascending order within each space sickness group at arbitrary but equidistant points along the x-axis for evaluation of the raw data. Black squares are mean (± S.D.) for each group plotted at the median position in the range of points; p values are from Mann-Whitney significance tests of the three sick groups separately tested against the NONE group.

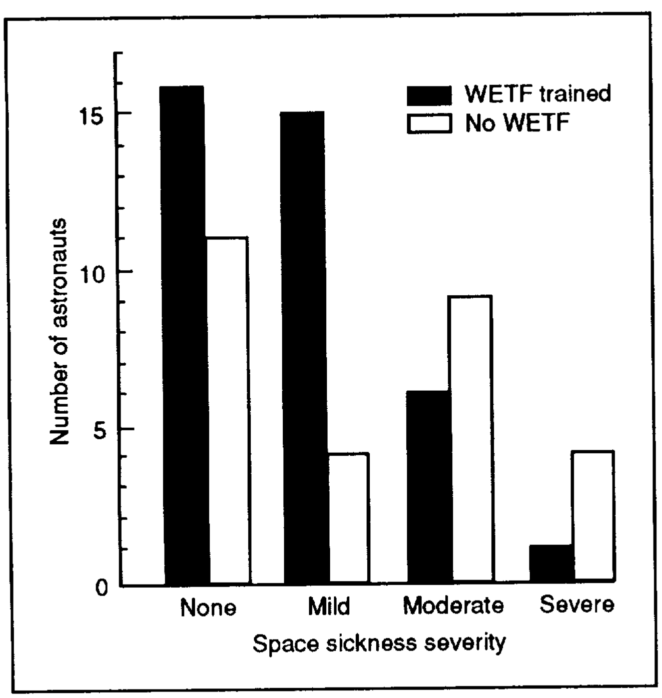

Figure 2. Presence and absence of WETF training relative to space sickness severity. The proportions of astronauts in the SEVERE and MODERATE groups who had WETF training and became space sick are less than in the NON and MILD groups. It appears that astronauts who might have otherwise been in the SEVERE and MODERATE groups were moved into the MILD group by their WETF training, but no astronauts were moved into the NONE group by WETF training (see also table I).

Evaluation of the LAMA RCH Hyperbaric Ventilator

TM:	**Charles W. Lloyd, Pharm. D./SD2**
PI:	**Michael Barratt, M.D./KRUG**
	Linda Murphy/MDAC
Reference:	**LS 18**

An automated ventilator is baselined for the respiratory support subsystem for Space Station Freedom (SSF) and is required to function in the Health Maintenance Facility, in the hyperbaric airlock (HAL), and during transport from SSF. Performance under hyperbaric conditions has been shown to be the limiting selection driver in choosing a ventilator. Crew Health Care System (CHeCS) personnel have tested several ventilators at the Johnson Space Center over the past 2 years under hyperbaric conditions. These have demonstrated lack of stability, in particular, loss of delivered tidal volume (V_T); frequency varying with treatment depth; difficulty in adjusting; hazardous electrical components; or some combination of the preceding. User friendliness is also an important working issue in choosing a unit for use in a man-power shortage area, as the HAL will be, and units tested thus far have fallen short in this area.

The Laboratoires De Mecanique Appliquee (LAMA) RCH ventilator was developed on a grant for the French Navy in 1980/1981, specifically for use in hyperbaric treatment chambers. The RCH is a volumetric, pneumatic, time-cycled ventilator designed for use from sea level pressure to 6 atmospheres absolute (ATA). Minute volume (V_M) and frequency are incrementally adjusted via prominent, forward-mounted toggle switches. Frequency is adjustable in increments of 5 breaths per minute (b/min) in a range of 5 to 35 b/min, and flow is adjustable in steps of 3 liters per minute (l/min) over a range of 3 to 21 l/min. Frequency is determined by a time-cycled logic cell that maintains a constant reference pressure through an ambient line. Inspiratory/expiratory ratio (I/E) is balanced at 0.5, and maximum inspired pressure spans the range of 20 to 80 cm H_2O. Positive end expiratory pressure is available and continuously adjustable from zero to 10 cm H_2O. An overboard dumping system, required for use in the HAL and other chambers, is integrated into the unit for rejecting expired gas outside the chamber. Visual and audio alarms indicate disconnection, gas circuit leak, or nonconformity to preset levels.

During the initial operational phase of SSF, known as the man-tended capability (MTC) phase, ambient Station pressure will be 10.2 psi rather than sea level. This is to reduce the pressure differential, and, hence, the risk of decompression sickness for crewmembers transiting from Station pressure to the lower suit pressure in support of extravehicular activity. Thus, the ventilator is required to function "at altitude" as well as "at depth." This report describes testing of frequency and flow stability of the RCH during unmanned chamber trials at depth and at 10.2 psi conducted by LAMA and CHeCS personnel.

Ventilator evaluation was performed at the LAMA laboratory, Etrechy, France. External reference pressure in these tests was 0.6 ATA; due to ventilator operational constraints, it was necessary to maintain a reference pressure below chamber pressure minimum, which is 10.2 psi or 0.7 ATA for the HAL and SSF during the MTC phase. Separate chambers were used for altitude and hyperbaric testing—initial settings were stabilized at sea level. Supply pressure (delta P) is generally 8 to 10 bars above local pressure, but minimal performance change results from a supply pressure of 6.8 bar if maximum treatment depth is 3.0 ATA. (For the HAL treatment profile, maximum treatment depth is 2.8 ATA.) A supply pressure of 8 ATA was used in the test. A test lung with a fixed calibrated compliance of 37 ml/cm H_2O was connected to the breathing circuit. An analog signal output was connected to a personal computer via chamber penetrators, providing calculations of frequency (F), M_V, and I/E balance. An in-line spirometer was not used.

Flow and frequency stability are depicted graphically in figures 1 and 2. The flow variation noted in figure 1 shows inflection points at 1.0 ATA—with greater relative variation between 1.0 and 0.7 ATA—and at 3.0 ATA, with a steepened decrease in flow during further descent to 4.0 ATA. This is most pronounced for the higher flow rates. Maximum change in flow over the treatment range of 0.7 to 3.0 ATA (2.8 ATA nominal) is 22.9 – 19.6 = 3.3 l/min, as seen on the top curve for the highest flow setting. This corresponds to tidal volume changes of from 1.18 l to 0.95 l

As noted in figure 1, a loss of V_M in the pressure excursion from 0.7 ATA (10.2 psi) to the nominal HAL treatment pressure of 2.8 ATA (41.1 psi) is seen; it is most pronounced at the higher flow settings. In comparison with other units tested, however, the RCH flow losses are relatively small and the V_M well maintains physiologically acceptable values. As is seen in figure 2, frequency is maintained extremely well under varying pressures, due to its constant reference to an ambient pressure (through the overboard dump circuit). Adjustment of the ventilator during descent to treatment pressure would probably not be necessary. A patient on a ventilator in the HAL will be extremely labor intensive to the lone medical attendant, who may or may not be a physician; the implications of having a "hands-off" ventilator are obvious. It must also be borne in mind that the MTC phase is transient, to cover 2 years of the 30-year life span of SSF; upon completion of the MTC phase, SSF pressure will be raised to sea level. There is minimal fluctuation in delivered volume between sea level pressure and treatment depth of 2.8 ATA.

The CHeCS personnel were also given the opportunity to conduct a manned chamber evaluation of the LAMA RCH. The ventilator was found to be simple to adjust with its large frequency and flow toggle switches, and represents a major enhancement in user friendliness over previous units tested. Incremental settings are more assured and more easily calibrated than are continuous rotary adjustments. Should it be deemed necessary to effect a compensatory change in flow during descent, it is probable this will involve a single switch input. Although spirometric function is not integral to the RCH, it should be incorporated into the breathing circuit to guide such adjustments quickly.

For the purposes of use on board SSF, other issues must be addressed. The off-the-shelf unit has dimensions of 40-by-14-by-19 cm and weighs 8 kg. It should be possible to decrease volume to 30% of original, and alternate housing materials should produce a lighter unit. The RCH will also require assessment as a transport ventilator, proving resistance to the effects of microgravity, sustained hypergravity during reentry, and impact forces during landing. It must be able to function with source pressures provided by the portable oxygen supply during the transport mode. Materials must meet safety, offgassing, and flammability requirements. It is also noted that the overboard dump circuit cannot be directly exposed to vacuum; an interim regulator providing a reference pressure of 0.6 bar will be required.

In conclusion, the LAMA RCH most closely meets the medical requirements for a ventilator for use on SSF, as outlined in the document JSC-31013, "Requirements of an Inflight Medical Crew Health Care System (CHeCS) for Space Station." It is stable in the hyperbaric environment and remarkably easy to adjust. Further testing is warranted, which should include the following:

- Use of a test lung capable of multiple compliance settings
- An exhalation circuit spirometry with a respiratory flowmeter
- Better characterizing source pressure needs under varying ambient pressures and lung compliances
- Testing under microgravity and hypergravity conditions for stability in parabolic flight (this is tentatively scheduled for early 1992)

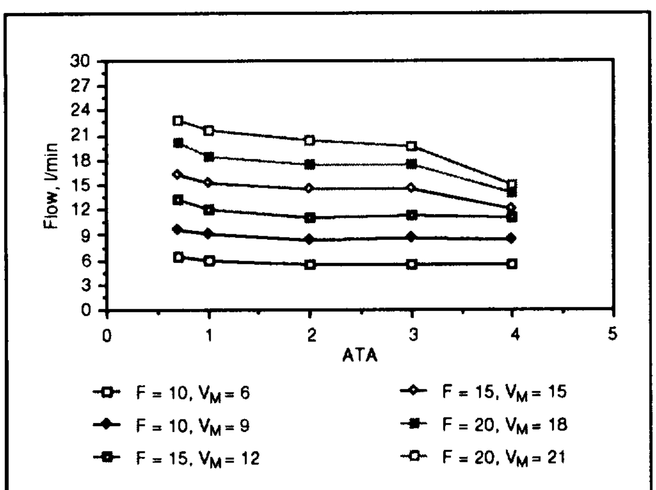

Figure 1. RCH flow stability at varying chamber pressures.

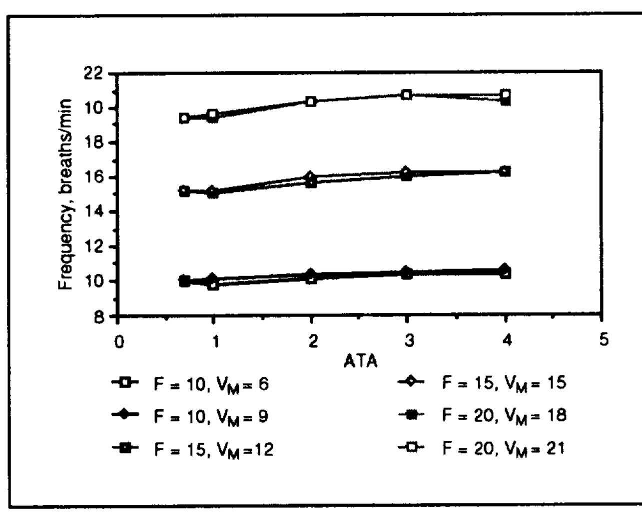

Figure 2. RCH frequency stability at varying chamber pressures.

Phase II Development of a Surgical Support System for Space Station Freedom—A Microgravity Animal Surgical Model

TM:	**Roger D. Billica, M.D./SD2**
PI:	**Smith L. Johnston III, M.D./KRUG**
	Mark R. Campbell, M.D./KRUG
Reference:	**LS 19**

In the first phase of development of the surgical support system for Space Station Freedom, the problems of performing minor surgical procedures in microgravity were reviewed and tested. It was noted that after proper restraint of patient, operator, instruments, and all equipment, the procedure and techniques were not grossly different than those at one g. The main problems to be solved involved prevention of spacecraft atmosphere contamination from blood and other body fluids and protection of the operative site from the high particle count of the spacecraft atmosphere. Also noted was the lack of surgical experience in microgravity—only the U.S.S.R. has performed animal surgery in parabolic flight.

In Phase II simulations, development surgical procedures were performed on adult, albino New Zealand rabbits weighing approximately 4 kg and sedated with a ketamine-based intramuscular injected cocktail. The procedures consisted of neck exploration with carotid artery incision and repair, followed by exploratory laparotomy, mesenteric vein incision and ligation, renal artery or abdominal aortic incision, and repair and wound closure. The procedures were performed on a series of three flights in the NASA Reduced Gravity Program utilizing a modified KC-135. A medical restraint system (MRS), consisting of an examining table, provided restraint of the animal and operating equipment. The MRS also provided restraint for the surgeons with a low, horizontal foot bar that had been designed and tested on previous flight experiments. The ability to provide adequate protection of the cabin atmosphere using local control (sponges and suction), a regional laminar flow device (LFD), and a surgical overhead canopy (SOC) to contain blood, irrigation fluid, and surgical debris were evaluated.

The SOC consisted of a clear Lexan®, sterile enclosure, 100-by-65-by-40 cm, held in place by a wire frame and containing two pairs of armports with sleeves on each side for the operating personnel and a large access door on one end to deliver supplies. The enclosure contained six large pockets on the inside for either temporary storage of sterile supplies or disposal of sterile trash and six large adhesive strip areas for disposal of small pieces of sterile trash (such as cut suture ends). In contrast to previous chamber designs by Markham and Rock, there was no floor to the enclosure, making it more adaptable to use on different operating field contours. The canopy was large enough to fit over the animal, a regional LFD, and a surgical tray.

The LFD consisted of a support structure attached to the MRS and located inside the SOC, which produces a regional horizontal sheet of laminar airflow across the surgical field after filtration through a 99.99% high-efficiency particle absorbing filter. The LFD also contained a suction device that collected the airflow and the particles of debris after passage over the surgical field. In addition, it acted as an attachment point for the surgical tray.

The surgical tray was designed as a 40-by-42 cm sterile tray that attached to the LFD and contained five areas for supplies and instrument fixation. There was a large magnetic area for securing ferrous instruments, a styrofoam block for sharp objects (needles and knife blades), and three areas with different-sized elastic cords for restraint of miscellaneous supplies. All instruments and supplies were prepackaged on the tray, which was opened at the start of the procedure and attached to the LFD.

The procedure pack was a 45-by-55 cm sterile field that attached to a wall-mounted rack and contained different size pockets for storage of sterile instruments and supplies. The pack is analogous to a "surgical back table" in a conventional operating room. The SOC, LDF, and surgical tray are illustrated in figure 1.

The use of an animal model was found to be vital in the completion of a realistic evaluation of hardware and procedures. The observation of arterial and venous bleeding in microgravity occurred. Interestingly, it was found that, due to the large surface tension forces of microgravity, fluid domes would form that could be easily controlled by local methods such as sponges and suctioning, as demonstrated on earlier KC-135 flights using a simulated bleeding model. This should be adequate to prevent cabin atmosphere contamination, unless a procedure generating a large amount of irrigation fluids, bleeding, or purulence is encountered.

Previous KC-135 flights have shown the importance of the restraint of operator, patient, equipment, instruments, supplies, and even discarded trash. It was found that standard surgical techniques and the ability to maintain a sterile field were extremely similar in difficulty to the one-g procedures with proper restraint. The ability to access sterile supplies quickly and deliver them to the surgical field is of importance to the efficiency of any surgical procedure. A supply management system utilizing a sterile, prepackaged surgical tray and a procedure pack acting as a sterile back table allowed this to occur. In the small volume of a spacecraft cabin with the rigid constraints on cabin atmosphere, the orderly disposal of discarded supplies becomes critical. Although the SOC allowed the ability to keep discarded articles controlled and together as a unit, a more sophisticated method of final disposal of dry, wet, and sharp articles will need to be developed.

The LFD was shown to be valuable in keeping the surgical field clear and in providing a low particle count environment for the operative site. Future prototypes will need to be smaller, more adaptable for human use, and provide a higher controlled rate of airflow and suction. The SOC was shown to be necessary in situations where fluids encountered could not be controlled by local methods. It also can provide attachment points for supplies, trash, and equipment and can facilitate the maintenance of a sterile field. Future prototypes will need to be smaller in weight and volume, easier to deploy, and could use a wall as an attachment point for a surgical tray. A sterile floor added to the SOC would create a more complete sterile field and allow restraint points for supplies closer to the operative site, but would also diminish the flexibility of its use in a true clinical situation.

The first NASA experience with a microgravity, surgical animal model and its importance in the design and evaluation of prototype hardware and procedures for the surgical support system of Space Station Freedom were demonstrated. This model should continue to expand the evolution of invasive critical care medicine in the space environment.

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Figure 1. The SOC, LDF, surgical tray, and two operators.

Human Support Technology

Summary

Human Support Technology

The Human Support Technology section includes a variety of disciplines. Predominant in it is the use of computers by people to perform tasks more easily, accurately, and efficiently.

Physical models of human beings start the section, emphasizing the "human." These models are empirically based, and both the models and the data collection equipment are described.

The use of computers to track people and things is explained, followed by a series of descriptions of the Space Station Freedom (SSF) structure and assembly as seen from the user's vantage point. New technology is needed for the longer Shuttle flights that will precede the fully operational phase of SSF, and a trash compactor, an improved animal enclosure, and an in-flight beverage pouch are all now available. These all enhance the usability of the Shuttle from a human factors standpoint.

Aids for the operators of remotely operated robots are described. Remote operations are conducted on the Shuttle with the remote manipulator system (RMS) and will be conducted on SSF with Canadian and Japanese manipulators. Furthermore, the assembly of SSF will be based in large part on operations of the Shuttle RMS. The aids described include head tracking controls for cameras, leaving hands free for teleoperations; analysis of the complexity of multiple remote operations; evaluation of alignment aids for possible targets; the effect of camera placement on manipulator control; evaluation of two 3-degree-of-freedom hand controllers for constrained tasks; and computer feedback of end-effector forces and torques as an operator aid.

The human-computer interface (HCI) will be an ever-present reality in spaceflight. It must meet the needs of the user in as friendly and easily understood a manner as possible. A great deal of research has gone into making the HCI acceptable. It was tested by an astronaut science advisor in SLS-1. It has been prototyped for an electronic cuff checklist for extravehicular activity for astronaut evaluation. Interfaces to medical decision support systems were also studied, as were interfaces to geographical information systems. A number of studies went into preparing the SSF Flight Human-Computer Interface Standards (SSP30570), including studies of interfaces to electronic procedures, interfaces to multitasking, and studies of cursor control devices. Tools and methods for user-intelligent system interaction design are described.

An assessment has been made of the human factors of spaceflight, with special focus on the Spacelab mission SLS-1 (STS-40). Looking forward to explorations of the Moon and Mars, the Apollo device for simulating 6-degree-of-freedom motion in partial g has been renovated and upgraded for future human factors studies, such as suit mobility and tool utility.

Because so many of the spacecraft systems and ground support systems depend on software, significant efforts have been made to develop intelligent software aids. The C Language Integrated Production System, developed at Johnson Space Center, has been widely picked up and used by other groups doing artificial intelligence (AI) work. Training is a major application of AI, and three systems for intelligent tutoring are described. Tools for developing AI programs are also described. The newest entry in AI, neural nets, are described in some of their applications, as is another recent entry: fuzzy logic.

The breadth of tools for support of the crew and the mission support teams—trainers, planners, and controllers—is captured in this section.

Human Support Technology

Significant Tasks

Computational Human Factors: A Dynamic Human Strength Model

PI: Jim Maida/SP34
Abhilash Pandya/LESC
Ann Aldridge, Ph.D./LESC
Barbara Woolford /SP34
Scott Hasson, Ph.D./
Texas Women's University
Reference: HST 1

Computer-aided engineering (CAE) is commonly used in many aspects of aerospace engineering. Extensions and enhancements of these useful tools of analysis are now beginning to be applied to the complex area of human modeling. The overall goals of such systems include analyses of the performance capabilities of a given individual or population in a specific environment. This is a multifaceted problem. The issues of anthropometric representations, kinematic articulation of joints (reach), vision, and strength are just a few examples of the areas of complexity involved. One of the research areas at the Graphics Analysis Facility (NASA/Johnson Space Center) is the development and validation of a dynamic strength model for humans.

Unlike earlier attempts at strength modeling, which were based on rotational spring and damper systems, our model is based on empirical data. The shoulder, elbow, and wrist joints were characterized in terms of maximum isolated torque, position, and velocity in all rotational planes. This information was reduced by a least squares regression technique into a table of single-variable, second-degree polynomial equations determining torque as a function of position and velocity (e.g., Torque = a + b* Angle + c* Angle**2, where a, b, c are the polynomial coefficients). The isolated joint torque equations were then used to compute forces resulting from a composite motion—which, in this case, is a ratchet wrench push-and-pull operation (fig. 1). The force/torque calculations were dependent on the geometry of the human figures, orientation, and computed motion (inverse kinematics) to convert the measured isolated joint torque to forces at the end effector (fig. 2).

Results indicate that forces derived from a composite motion of joints (ratcheting) can be predicted from isolated joint measures. Model versus measured values for 14 subjects were compared. Calculated T values (a standard statistical measure) were well within the statistically acceptable limits (alpha = 0.01), and regression analysis revealed the coefficient of variation (R^2) between actual and measured to be within the 0.72 to 0.80 range. Moreover, the model is flexible in terms of the environments and human motions that can be modeled.

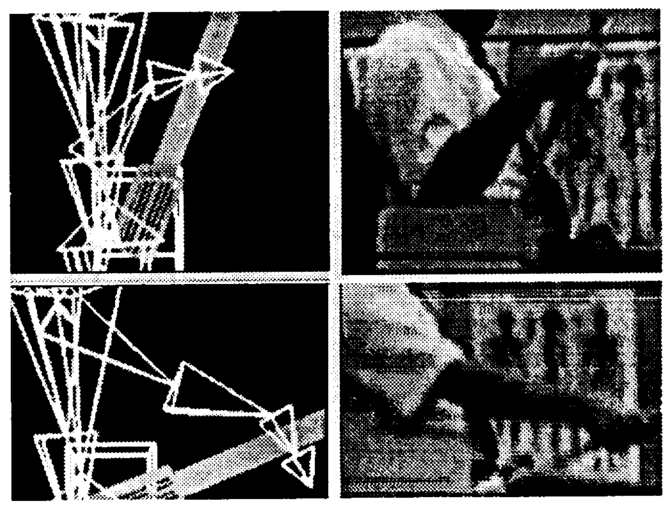

Figure 1. Model versus actual ratcheting.

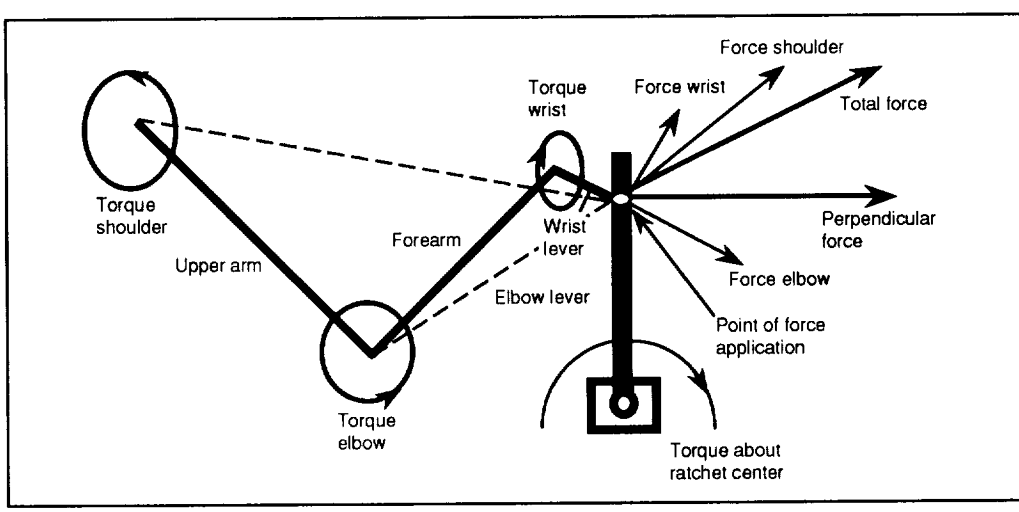

Figure 2. Diagram illustrating force vector propagation.

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Prediction of Human Isolated Joint Strength From Lean Body Mass

PI: Jim Maida/SP34
Abhilash Pandya/LESC
Ann Aldridge, Ph.D./LESC
Barbara Woolford /SP34
Scott Hasson, Ph.D./
Texas Women's University

Reference: HST 2

A relationship exists between a person's lean body mass and the amount of maximum torque that an individual can produce with each isolated joint of the upper extremity. The use of an easily measured parameter (lean body mass) to predict dynamic isolated joint torque, which is time-consuming to measure, would be extremely valuable. At the Man-Systems Graphics Analysis Facility (NASA/Johnson Space Center), maximum dynamic isolated joint data have been collected on 14 subjects for the upper extremity, and a regression model has been formulated that will allow prediction of a joint angle versus torque curve for a particular individual.

Phase one of the study involved measuring the maximum torque for all the upper extremity joints (shoulder, elbow, wrist) for 14 subjects. Dynamometer attachments were selected and placed so as to isolate the joint being measured. In this manner, all joints were characterized for all axes of rotation over a range of velocities. For all cases, the data set consisted of torque and angle pairs.

The second phase of the project involved computing polynomial coefficients from the data, using a least squares regression method. These polynomials represented the torque as a function of angle. All the polynomial coefficients were then organized into look-up tables. These tables represent a compact and convenient storage/retrieval mechanism for the entire data set and are available upon request.

The third phase of the project involved model formulation. Data from each joint, direction, and velocity of an individual were normalized with respect to that joint's average and merged into files (one for each curve for a particular joint). Regression was performed on each one of these files to derive a table of normalized population curve coefficients for each joint axis, direction, and velocity (fig.1). In addition, a regression table was built that included all upper extremity joints and related average torque to lean body mass for an individual. These two tables are the basis of the regression model, which allows isolated joint curve prediction.

Finally, we have encapsulated the results of this study in a tool kit of software routines executing on a variety of platforms [UNIX, DOS, Macintosh machines]. This code contains our isolated joint torque model (with all the tables of torque coefficients) and will allow the prediction of dynamic isolated joint torques of the upper extremity from an individual's lean body mass (fig. 2).

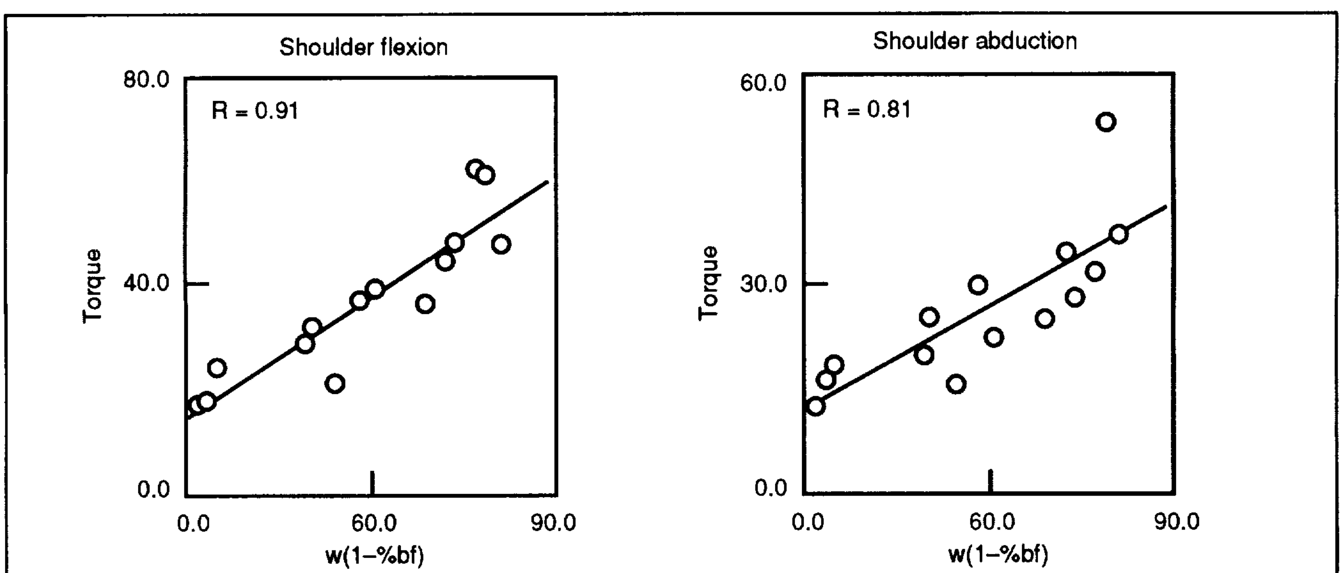


Figure 1. Lean body mass versus torque for shoulder at 120°/sec.

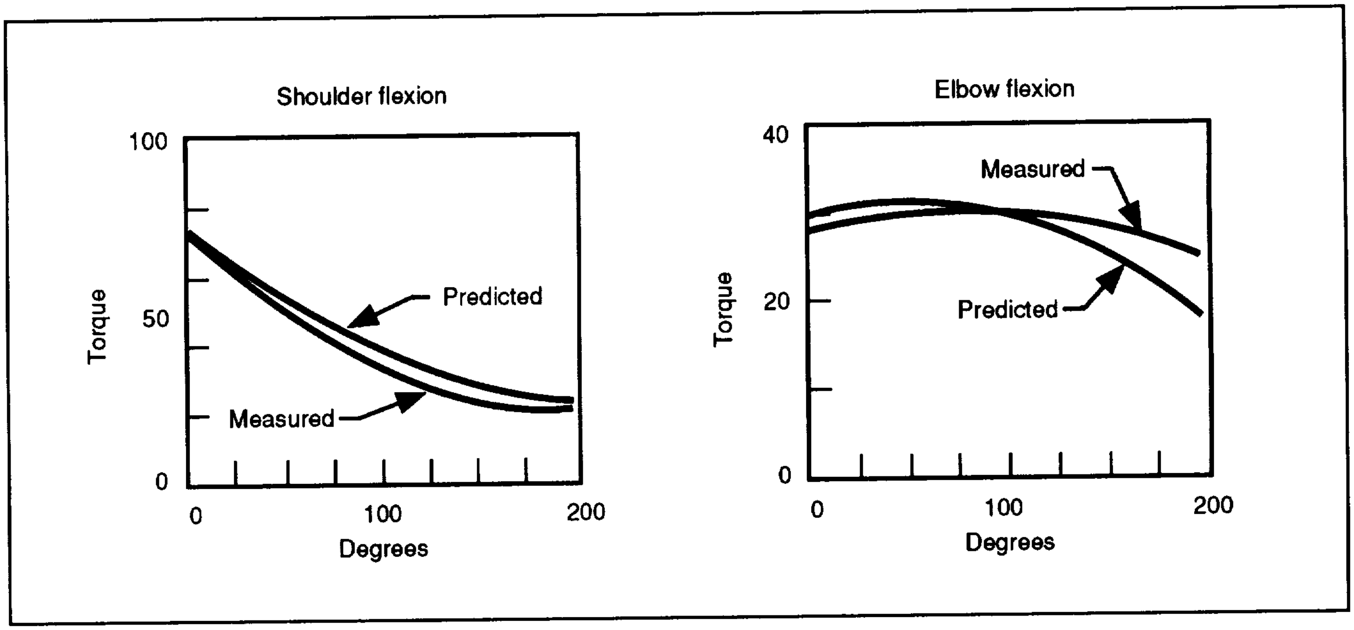


Figure 2. Predicted versus measured isolated joint torque from only lean body mass.

Muscle Strength Measurements

PI: **Glenn K. Klute/SP34**
Lauren Schafer/LESC
Reference: **HST 3**

Investigations of muscle strength—whether it be the ability to exert a force to move a large instrument rack on Space Station Freedom, torque a fastener on an orbital replacement unit, or assemble a Space Station truss—is an important area that defines human performance.

The capability to perform tasks in the microgravity environment of space is a frequent subject of investigation in the Anthropometry and Biomechanics Laboratory (ABL). The ability of a crewmember to exert forces and torques on objects in zero-g conditions can have a direct impact on the success of a mission. Measurement of these parameters drives design specifications for items such as hatch locks, foot restraint systems, handholds and translation aids, and extravehicular activity (EVA) suits, as well as numerous tools for both EVA and intravehicular activity tasks.

Isokinetic dynamometers are used in human performance testing to measure the mechanical properties of muscle under constant angular velocity conditions (fig. 1). These devices are ideally suited for examining muscle strength of both isolated and multiple joints while performing specific tasks. An advanced isokinetic dynamometer is currently being modified for use in zero-g simulation facilities at the Johnson Space Center (JSC).

The dynamometer (manufactured by Loredan, Inc.) under modification has the capacity for torque measurements of up to 300 ft-lb and an angular velocity rate of up to 300°/sec. Computer control facilitates test operations, parameter measurement, and data reduction. To allow the use of this device in the JSC zero-g simulation facilities, several modifications were required.

The KC-135 aircraft provides periodic reduced-gravity capability during parabolic maneuvers. Use of the dynamometer on the aircraft required structural modifications to withstand a 9g forward crash load. The Weightless Environment Training Facility is a neutral buoyancy facility that simulates the zero-g environment. To allow operation in this environment, the dynamometer is being modified to be waterproof to a depth of 66 ft.

Applications of these investigations include the design of tools for effective use in microgravity, the identification of suit limitations—which has had the effect of increased crewmember productivity—and many other physical strength-related tasks. Experiments of this nature in the laboratory allow for repeatable conditions with measurable experimental parameters prior to use and application during a mission.

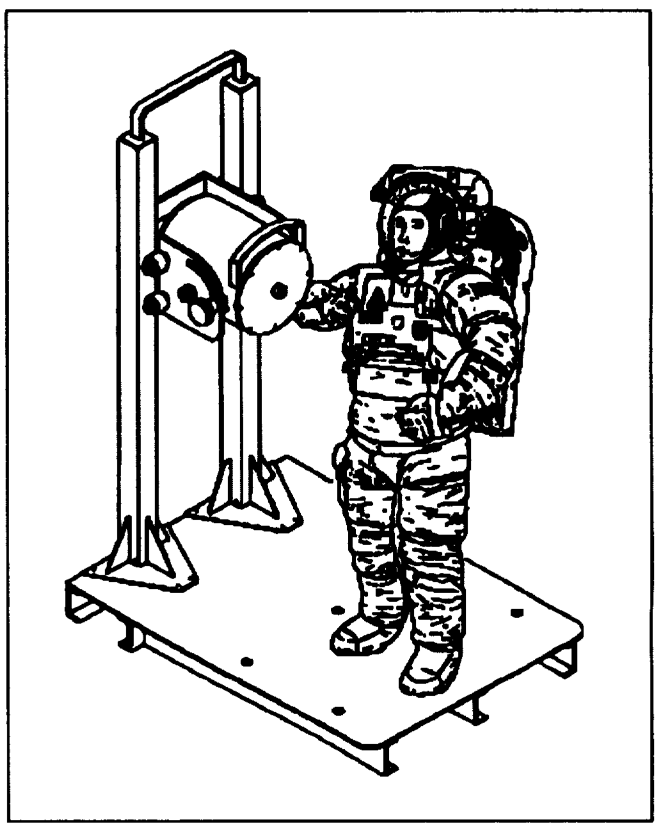


Figure 1. Isokinetic dynamometers are utilized for human performance testing by the ABL.

Computer Aided Tracking System

PI: L. W. Lew/SP33
Reference: HST 4

In the course of its expected 30-year life, the Space Station Freedom (SSF) crewmembers will have to contend with hundreds of thousands of individual items to be used, consumed, and replaced in normal day-to-day onboard operations. The size and complexity of these items will range from as small as a chapstick to telephone-booth-sized subsystem components. Since the crew will be operating in a remote environment with periodic resupply capability, it is essential to safety and productivity to properly stow, track, and account for each item on board SSF. Doing this quickly is a goal for designers and operators of the Station to achieve.

For the SSF Program, a comprehensive data base must be established and maintained for all phases of the mission (launch, on orbit, and return) for many different habitable elements. It is imperative that critical data base parameters be accurately tracked and sorted for an ever-changing and dynamic environment to meet program requirements.

An in-house project is under way to develop an innovative computer graphic data base management system in which graphical information is linked with the data base management system. The system will not only enable the user to visualize items, it will associate information to the contents of the graphical data (figs 1, 2, 3). System capabilities will include sorting and tracking of items, ability to move items between different stowage locations (e.g., racks, elements, etc.), instant updates of data base changes through all levels, and the ability to create or edit graphics for new modules or design changes. The system will be a powerful computerized visual management system that can be used real time by multiple NASA organizations, including the Mission Operations Directorate (MOD) flight controllers.

In addition, to ensure a successful completion of the project, a Small Business Innovative Research Phase I project has been awarded to Aptek, Inc., for development of a similar Space Station Stowage Data Base Management System. This project will be completed in 1992.

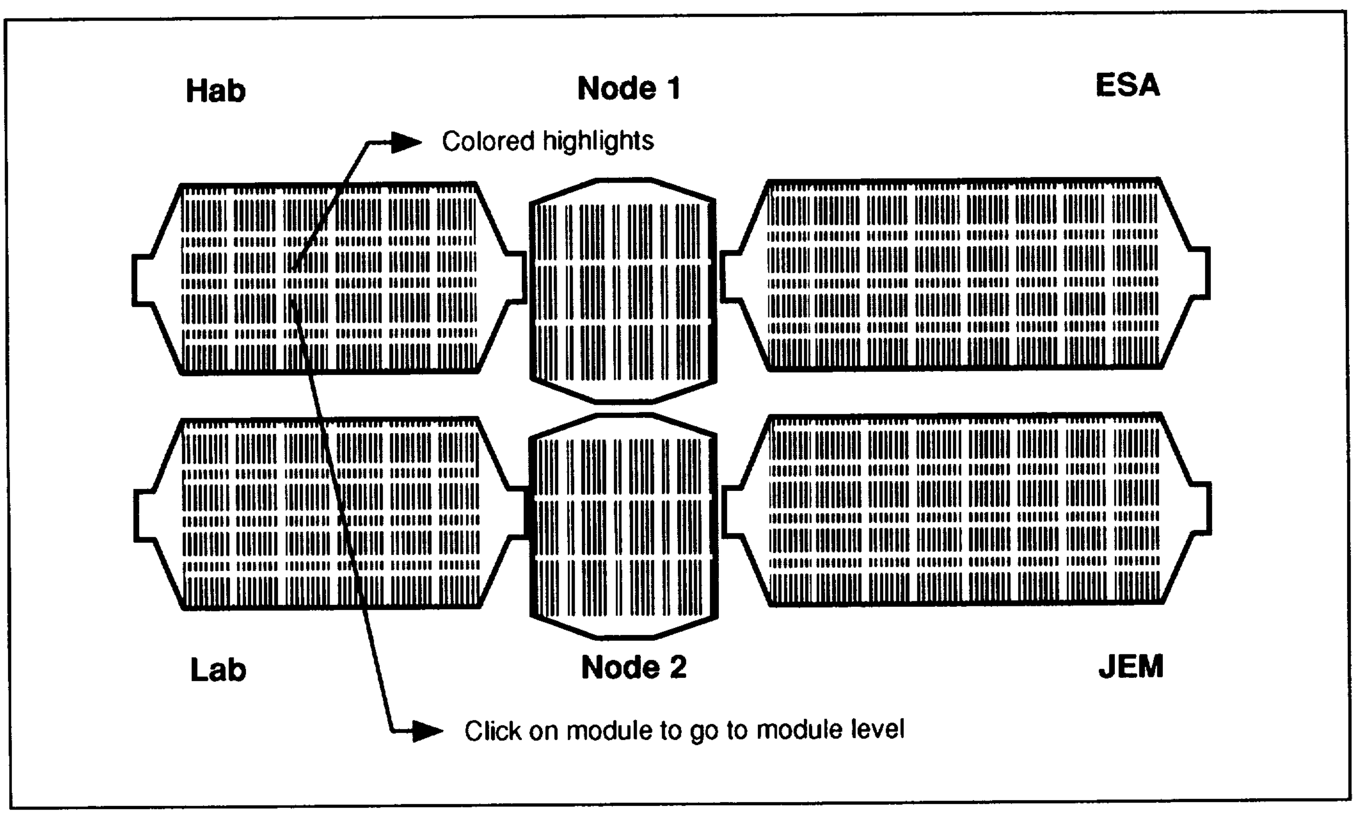


Figure 1. Space Station schematic.

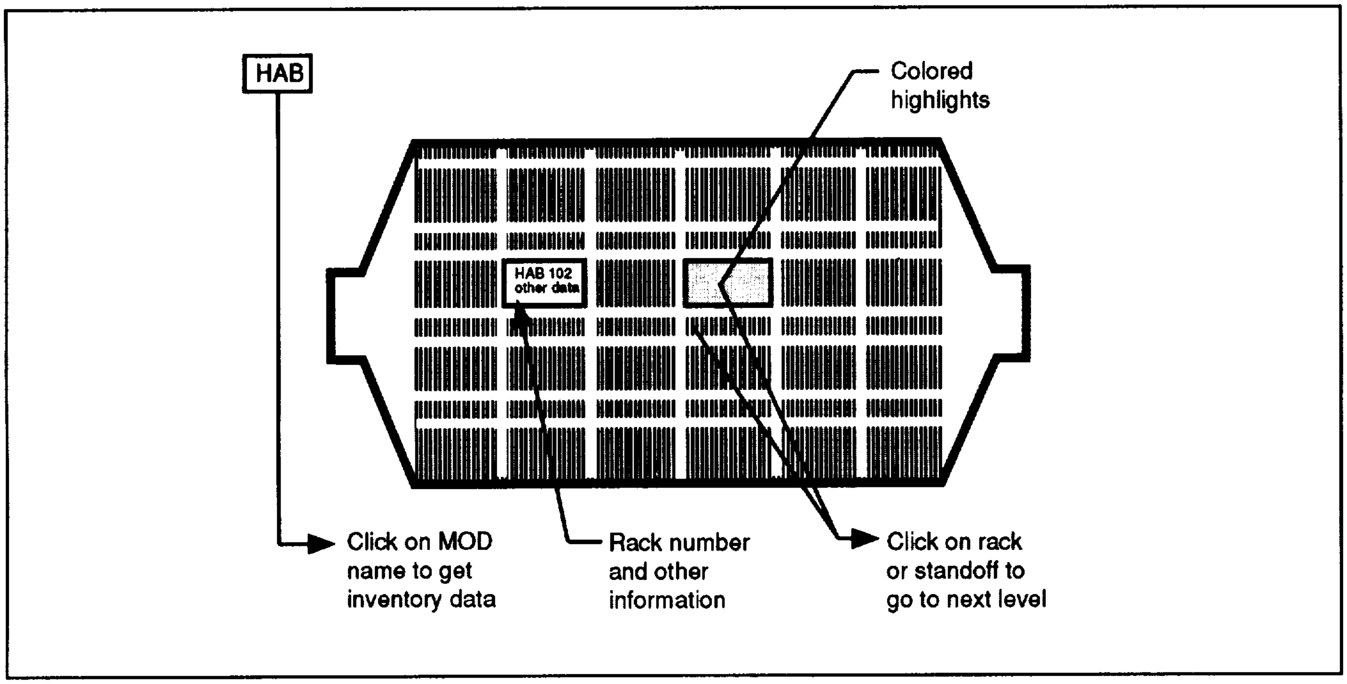


Figure 2. Module schematic.

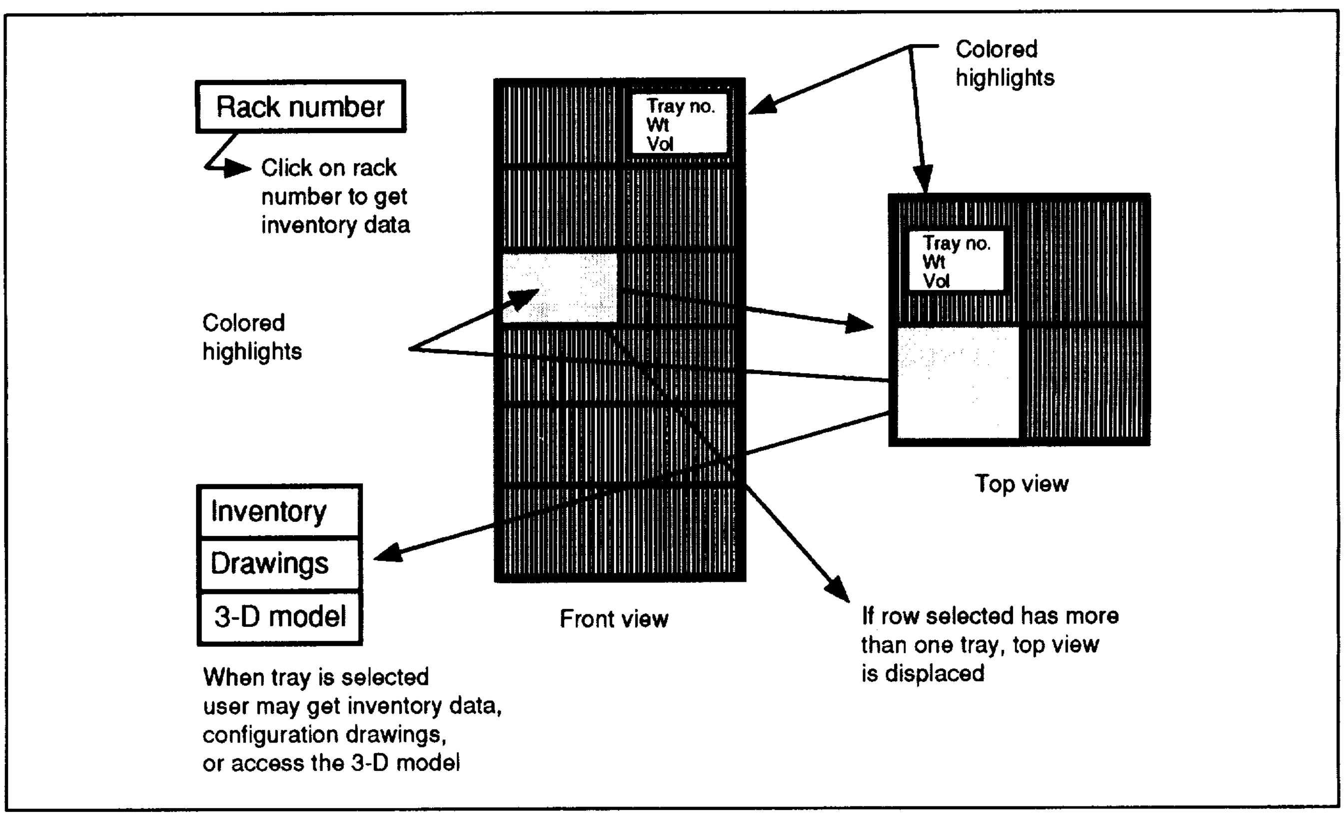


Figure 3. Rack schematic.

Weightless Environment Training Facility Diver Tracking System

PI: **Leslie Schaschl/SP54**
Mike Cochran/Cochran Consulting, Inc.

Reference: **HST 5**

The Weightless Environment Training Facility (WETF) is involved in the research and development of the diver tracking system (DTS), a multifaceted dive computer. As with the commercial dive computers, the DTS will track the depth, maximum depth, tank pressure, remaining no decompression time, tissue saturation, time to fly, and surface interval. However, in addition to displaying these parameters on a wrist unit, they are also sent to a topside computer via magnetic antennas for display on a cathode ray tube (fig. 1). A sample display will show such parameters as #S (serial number of the tank unit), VC (voice channel), name (name of diver), DPT (depth), TANK (tank air pressure), RAT (remaining air time), RNDC (remaining no decompression time), DEC (time at each decompression stop), BP (breathing parameter), BOTT (bottom time), and SURTIME (surface time) (table I). This will allow a topside operator to monitor all parameters, noting which diver has the lowest tank pressure, time remaining for "no decompression" dive, etc.

At the present time, the WETF does not conduct decompression dives as the pool is only 25 ft deep, and the maximum time allowed for diving during a test run is 2 hours. When the Neutral Buoyancy Laboratory, a 40-ft deep pool, becomes operational, the features being displayed will be extremely valuable in monitoring the nitrogen levels and remaining air time of each diver. Actual nitrogen values can be calculated by taking into consideration the variable depth of the diver so that maximum amount of dive time is utilized before decompression time is warranted.

Additional research and development is being conducted on upgrades to the system, such as voice capabilities and diver positioning capabilities. The voice system will allow the divers to talk through the test loop via a small mouth chamber, giving real-time inputs and directions. A receiver will be positioned behind the diver's ear for audio. The positioning system will allow a topside operator to monitor the position of the divers during a test.

TABLE I. SCHEMATIC OF SAMPLE DTS COMPUTER MENU

SA	VC	NAME	DPT	TANK	RAT	RNDC	DEC	BP	BOTT	SURTIME
1	B	BAILEY	7	1000	1:20	4:00		8	0:30	0:16
2	B	BEACHAM	15	2700	2:50	3:00		5	1:15	0:20
3	A	BEGNAUD	25	1200	1:00	2:00		11	1:15	0:05

MAIN MENU-SELECT FUNCTION	TURN MENU-OFF	VOICE UTILITIES
INITIALIZE UNIT	TURN UNIT	
ACTIVATE UNIT	CLEAR UDC PARAMS	
INACTIVATE UNIT	OPEN LOG FILE	POSITIONING UTILITIES
EXCHANGE UNITS		
(RE)ASSIGN WRIST	EXIT TO DOS	
OPTIONAL DATA		

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

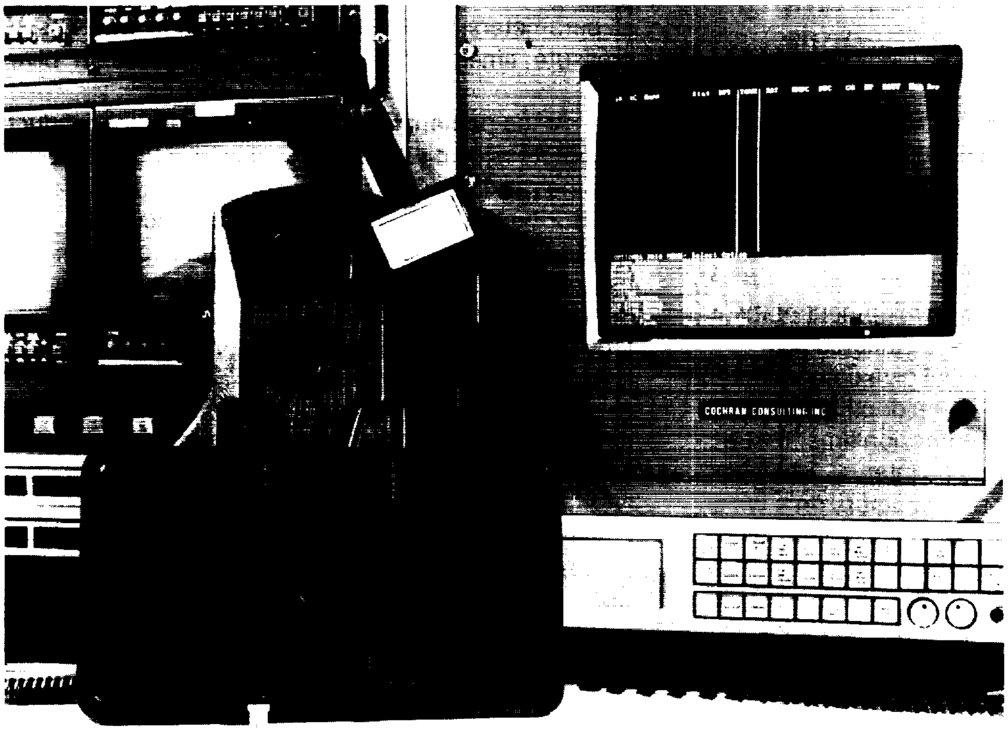


Figure 1. DTS hardware.

Crew Concept Maintenance Workstation

PI: Frances Mount/SP34
Jason Beierle/LESC
Reference: HST 6

Skylab flight experience has shown that long-duration space habitats should include a dedicated facility for performing hardware maintenance and repair activities. This maintenance facility should also provide stowage for relevant tools and equipment necessary to accommodate the tasks. In response, a maintenance workstation (MWS) to support on-orbit maintenance has been prescribed by program planners as a necessary fixture on board Space Station Freedom (SSF).

As originally baselined, the MWS would consist of two adjacent Space Station double racks approximately 84 in. in total width. The unit would be a contained air-cleansing facility for filtering particulate matter and gaseous pollutants generated by maintenance tasks. In addition, the MWS would provide stowage for tools and test equipment and a work surface/work volume designed to accommodate hardware requiring repair. The concept maintained the ability to accommodate two crewmembers working simultaneously on a complex task.

Decreases in SSF Program funding resulted in the currently accepted "phased approach" to SSF buildup. This "phased approach" challenged the MWS functionality since only one-half of the MWS (1 double rack) would be launched in Lab A at the man-tended capability (MTC) phase. The other half would arrive years later at the eight-man crew capability (EMCC) phase. Because of the lengthy time between MTC and EMCC, analysis of the acceptability of the one-rack MWS design was considered necessary. NASA's Man-Systems Division performed a volumetric study to show the impacts of the redesign. The study revealed the substantial disadvantages of the small single work volume in accommodating two operators, repair equipment, and repair items. The baselined MWS design was determined to be unacceptable to both the MWS task monitors and representatives for the user population, the crew. The crew experienced, in zero g, maintenance tasks specified as design criteria: maximum stowage capability, large work/restraint area, two operator accommodations, easily viewed test equipment displays, and incorporation of an overall flexible/functional design. This information was utilized in the process of conceptualizing what is referred to as the crew concept maintenance workstation (CCMWS, fig. 1).

To fulfill the requirements and crew criteria for the accommodation of large hardware and two operators, the CCMWS conceptualizes the utilization of the corridor as the maintenance work area. It has been determined that maintenance tasks within the corridor can be tolerated on a part-time, short-duration basis for contingency repair. Restrictions—such as infringement upon adjacent rack areas, access to pressure walls, and ease of set up/breakdown and storage of any temporarily constructed workbench hardware—were considered. This approach to the design also allows a large percentage of the rack to be utilized for the stowage of tools and analysis/test equipment. Design details include a partially or fully deployable work surface, a channel groove restraint system, the use of a flexible "baggie" for control of contaminants, and tool caddies and integrated diagnostic equipment that detach for portable use.

The work on the CCMWS resulted in the construction of a full-scale, representative mockup at the Johnson Space Center. The CCMWS mockup served as a tool for reviewing design details and the configuration orientation in the laboratory module of the SSF mockup. The new MWS concept to reflect the SSF weight and budget impacts was baselined in September 1991. This new design incorporates many of the features of the CCMWS.

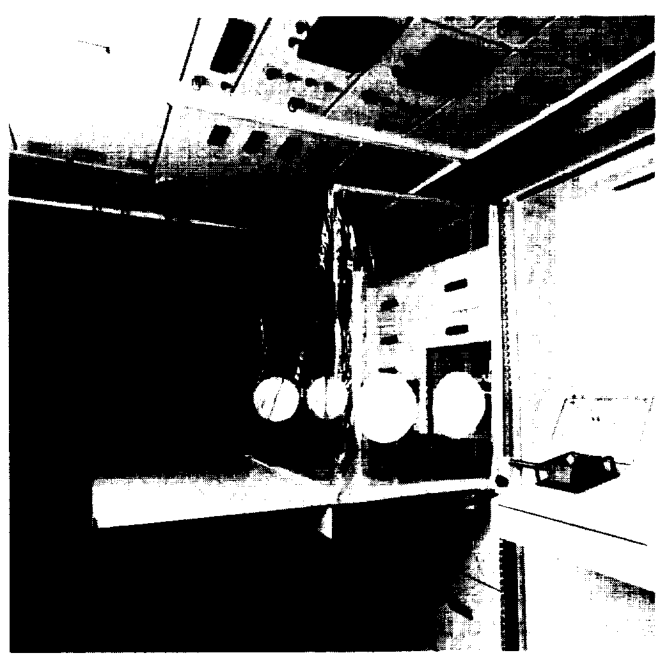


Figure 1. CCMWS mockup.

Viewing Analysis for the Assembly of Space Station Freedom

PI: **Frances Mount/SP34**
James Malda/SP34
Sheryl Stealey/LESC
Kim Tran/LESC
Reference: **HST 7**

Analyses are currently being conducted in the Man-Systems Division of the NASA/Johnson Space Center (JSC) on the restructured Space Station Freedom (SSF) configuration (fig. 1) to determine viewing requirements for both robotic tasks and extravehicular crew activities. This initial analysis was undertaken to identify problem areas and to determine preliminary solutions pending further study. These analyses investigated the tasks for each mission buildup phase and determined whether viewing of these tasks was achievable directly from the available windows (either from the Orbiter or the Space Station) or by indirect means such as through video cameras. The use of the PLAID software, a 3-dimensional modeling simulation tool, provides a simulation of the environment and the system hardware to identify potential problem areas needing further refinement in design development. This process supports design refinement and validation, reducing the overall cost of design hardware. It also enables human factors considerations and issues to be explored during the design process, so problems may be identified and corrected before hardware is actually constructed.

Part of the restructuring process mandated a reduction in the number of extravehicular activity (EVA) tasks to be conducted during SSF construction. This reduction in EVAs significantly increased the number of robotic tasks needed for assembly. While this reduces the safety risks for the crew overall, it increases the need for direct viewing and camera viewing of robotic tasks. To accommodate robotic berthing requirements, orthogonal views are needed. These camera views must be sharp, clear, and have adequate lighting to convey the necessary information about depth, clearance, and proximity. Camera views are also needed of the EVA crew. For safety considerations, an EVA crewmember must be in view or in communication with other crewmembers at all times. To verify these circumstances for the restructured SSF configuration, several evaluations were conducted, utilizing the GRAF at NASA/JSC. The PLAID software was used to study the viewpoints of the crewmembers while they actually conducted assembly operations. These analyses were done under a worst-case scenario, where the SSF was in complete darkness with only the Orbiter and SSF lights available to aid viewing.

Preliminary results have indicated several viewing problem areas with the available lighting for both robotic and EVA tasks (fig. 2). Specific problems have been identified with robotic tasks such as the deployment of the beta gimbals, the attachment of the propulsion modules, the mating of the truss sections, and the berthing of the U.S. and international modules. Some examples of EVA problems are the mating of the utility tray connections, unstowing the Space Station remote manipulator system from the Orbiter payload bay, deploying the mobile transporter system (MTS), and installing the propulsion module attach structures. These problem areas are a representative sample from the tasks that must be completed safely and efficiently by the crewmembers before effective utilization of the Station can be achieved.

To rectify the viewing problems identified through simulation, additional cameras are being proposed at various sites along the truss and on the Orbiter to provide more complete coverage of work task sites. This includes placing additional lights and cameras in the payload bay for viewing the unstowing of hardware. Additional cameras will be placed on the truss to view the mating of the pit sections for truss attachment. Supplementing the existing cameras with color-coded alignment aids will reduce the workload involved with robotic tasks such as the deployment of the propulsion modules and the mating of the MTS and the unpressurized berthing adapter. Additional lighting is also being added for global viewing along the truss to improve general viewing conditions. These additions will allow continuous views of the crew while EVAs are being conducted.

These analyses, based on the new SSF configuration, have identified additional requirements for lighting and cameras, their placement, and the need for alignment aids. Employing these recommendations will greatly expedite the completion of the robotic berthing tasks and enhance crew safety. Further research is needed, though, to determine the optimal design that incorporates crew safety and the power and weight limitations currently placed on SSF.

Figure 1. Global view of the Space Station in its restructured configuration.

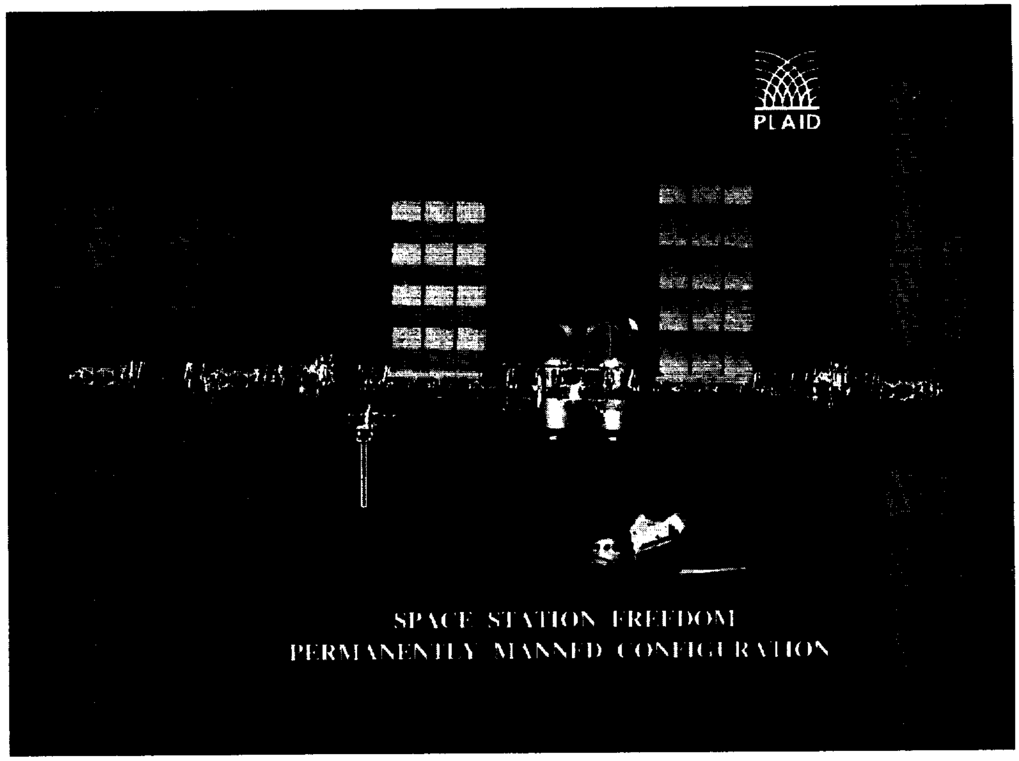
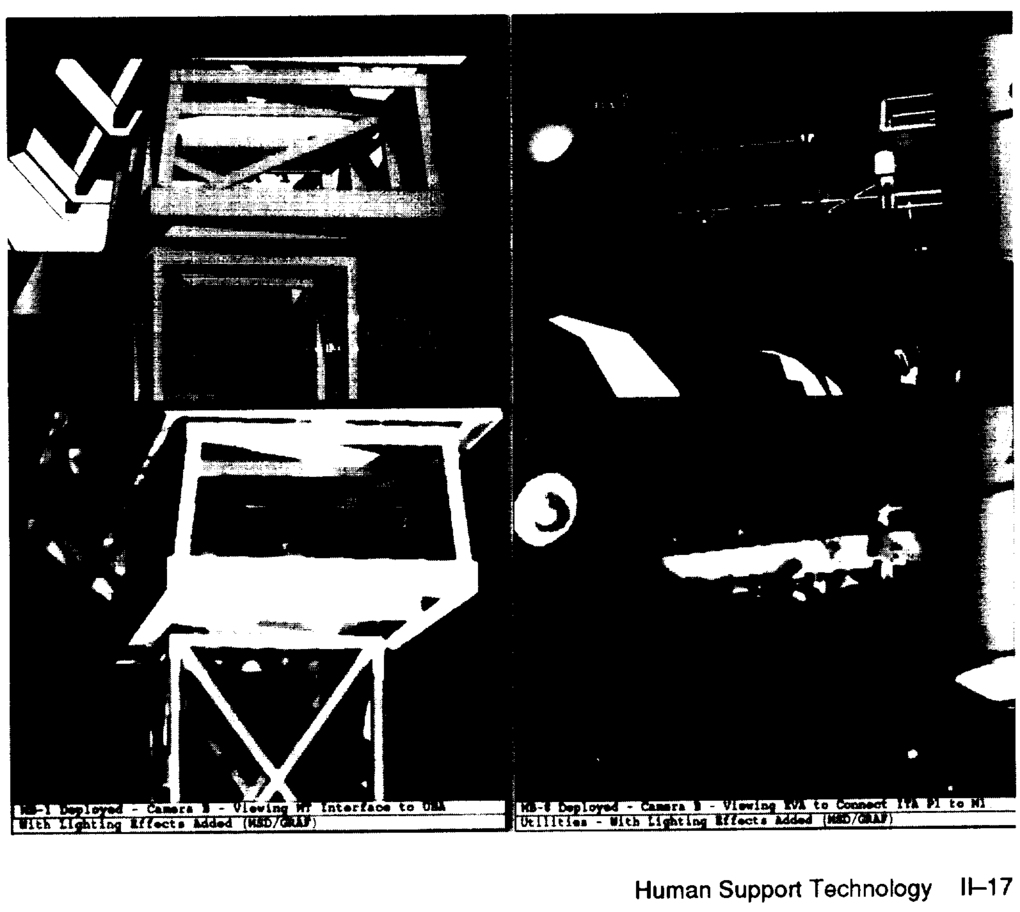


Figure 2. Two representative assembly problem areas. The second row shows the respective views incorporating SSF lighting, simulating the view as seen by the crew.



Evaluation of Current Cupola Configuration on the Space Station Freedom

PI: **Frances Mount/SP34**
James Maida/SP34
Sheryl Stealey/LESC
Lorraine Meagher/LESC
Kim Tran/LESC
Reference: **HST 8**

Analyses are currently being conducted in the Man-Systems Division of the NASA/Johnson Space Center on the restructured Space Station Freedom (SSF) configuration to determine viewing requirements for the cupola. This initial analysis was undertaken to identify problem areas and to determine preliminary solutions for further study. The SSF viewing requirements indicate that assembly and extravehicular crew operations should be viewed by direct means whenever possible. To accommodate this requirement, two positions for the cupola were evaluated. These two locations were the zenith side of node 1 and the port side of node 2. These analyses utilized the tasks from mission buildup (MB) missions 6 to 16 to investigate the node 1 and node 2 positions. The use of the PLAID software, a 3-dimension modeling simulation tool, provided a simulation of the environment and the Station hardware to identify potential problem areas needing further refinement during system development.

The first evaluation investigated the cupola viewing from the node 2 port side location. The operational tasks chosen were from MB-6 to -10. These tasks included deploying Lab A and attaching it to node 2, installing the mobile servicer system (MBS) onto the mobile transporter (MT), installing the airlock onto node 2, and installing the integrated truss assembly (ITA) onto the port truss structure.

Preliminary results of the first evaluation indicated that viewing payload bay activities for unstowing hardware was adequate. However, further analyses indicated that viewing from the cupola on node 2 was not adequate to complete the berthing tasks for the installation of Lab A and the airlock onto node 2. Analysis indicated that views of the attachment sights were not obtainable from the cupola in this orientation. This cupola position also does not allow the viewing of the installation of the MBS onto the MT. In this case, the view is blocked by the SSF truss structure. The addition of indirect camera views to show the attachment areas for the node, and the trunnion pin attachment areas for the Shuttle and Space Station remote manipulator systems are necessary to complete these assembly operations. Analyses also indicate that viewing the installation of the ITA truss section was blocked by the radiator panel. Viewing the ITA installation can be remedied by shifting the orientation of the radiator panel 30° from parallel to the truss. This will allow the viewing of the trunnion pin, which is necessary to complete this robotic arm task.

The second evaluation investigated the cupola viewing when attached to the zenith position of node 1. This is the proposed position it will be moved to at MB-11, and it will remain at this position through MB-16. The cupola position at permanently manned capability (PMC) is not determined at this point. The Assured Crew Return Vehicle is currently slated to occupy the zenith position of node 1 at MB-17, when SSF reaches PMC.

In general, viewing of the payload bay activities was not adequate from the node 1 position. Global views of the starboard truss section were available, but the port view beyond the airlock was not visible. In this case, the airlock itself blocked further viewing down the port truss structure. Viewing of the Japanese experiment module (JEM) facilities was poor due to the obstruction of the view out the cupola window by the workstation (fig. 1). Workstation redesign is indicated to reposition, and possibly lower its orientation, to obtain an unobstructed view through the window (fig. 2). Viewing of the robotic tasks and the actual viewing of attachment points and berthing operations is also poor from the node 1 position. Indirect viewing for these tasks, including the installation of the JEM external facilities and of the European Space Agency Columbus module, will be needed to safely complete these operations.

These analyses have identified several problem areas for both cupola positions investigated. To remedy these problems identified through simulation, additional cameras should be placed along the truss and on the modules to provide orthogonal viewing for berthing operations and module attachment. The actual camera port locations will be identified and evaluated in subsequent investigations. This initial investigation has focused on identifying potential problems and solutions. Other node positions for the cupola should be investigated to determine an optimal location, and to determine a position that satisfies the greatest number of Station requirements. Trade-offs will have to be made due to limited placement possibilities from the restructured SSF configuration. Another change that should be considered is the provision of greater visibility through the windows by either making the windows larger or by enlarging the cupola itself. This may not be possible due to funding, weight, and time constraints being placed on the Station design and development. Additional study will also be necessary to investigate the effects that lighting conditions may have on cupola viewing and placement.

Figure 1. Crew orientation at the workstation and the body position needed to view the Japanese module.

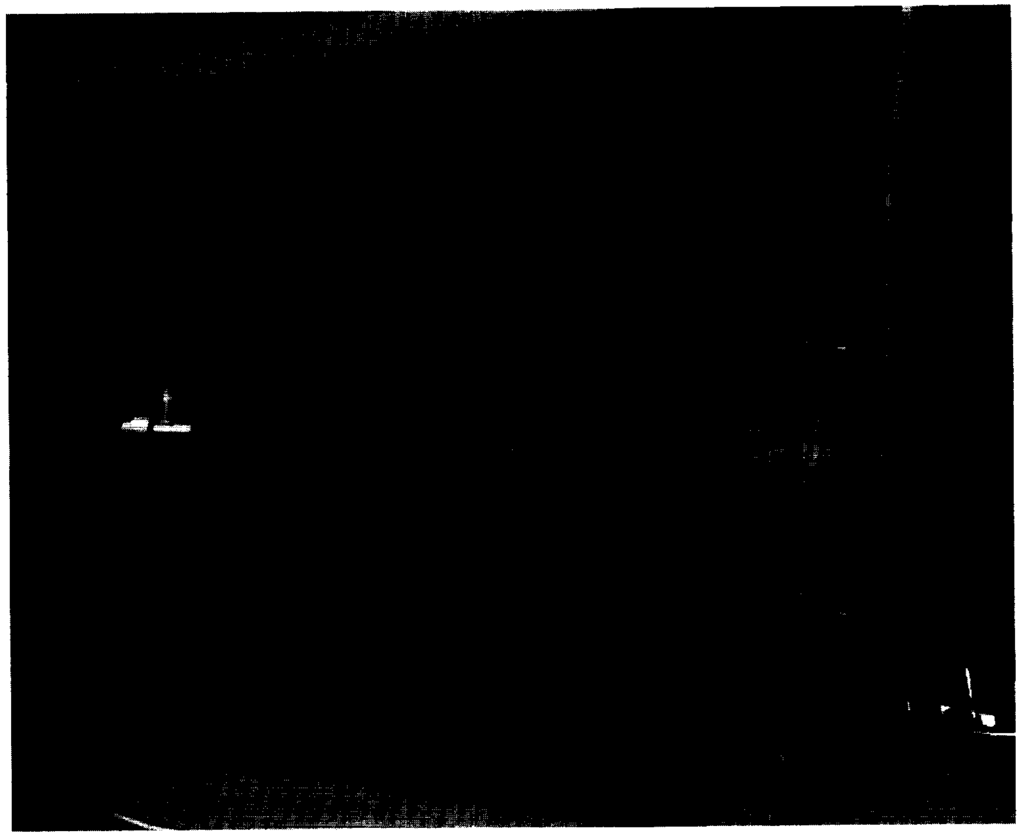
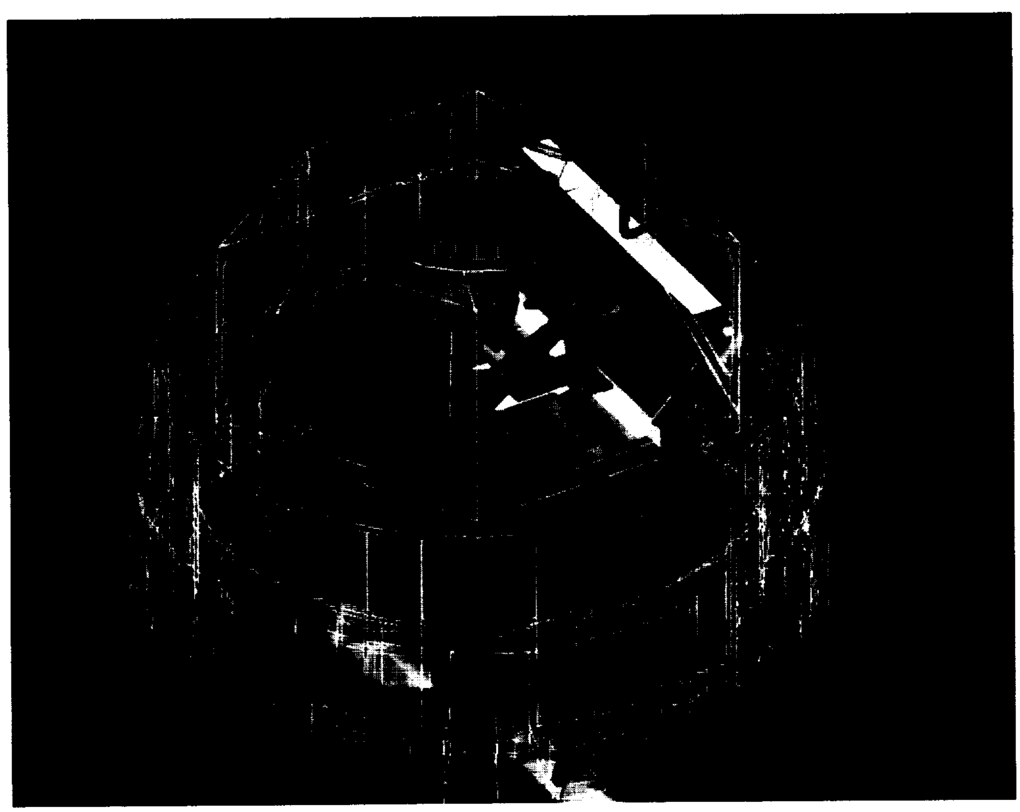


Figure 2. Crew view out the cupola window.



Extended Duration Orbiter Trash Compactor

PI: J. B. Thomas/SP44
Reference: HST 9

The trash compactor will become an important part of Shuttle hardware as NASA begins flying extended duration Orbiter (EDO) flights. The EDO missions will accumulate more trash in a vehicle where stowage space is already extremely limited. The first 13-day EDO mission currently is scheduled for 1992. Plans call for the first 16-day EDO mission to occur in 1994.

The goal of the EDO trash compactor is to reduce the trash to a manageable volume for EDO missions. Each crewmember generates approximately .5 ft^3 of trash per day. Current projections indicate approximately 56 ft^3 of trash will be generated on the first 16-day EDO flight, and the compactor should reduce that to 14 ft^3 of compacted trash. The 52-lb compactor (fig. 1) fits in place of a middeck locker and is operated manually. Trash is placed inside a polypropylene bag that, when full, is placed inside the chamber of the compactor. One bag holds a volume equivalent to .5 ft^3. A metal compactor door is closed, securing the bag inside the chamber. A crewmember then uses handles on either side of the compactor in a garden shear-type movement to engage gears that push a piston from the back of the chamber to the front, compressing the trash to a volume one-fourth the original (fig. 2). The piston compresses the trash with a force of about 60 lb/in^2. After the piston is moved as far as it is designed to go, the crewmember retracts it, opens the compactor door, pulls a strap to prevent re-expansion, and removes the bag from the chamber. The bag has a lid that houses a charcoal/gortex filter to contain odors, fluids, and bacteria. A one-way check valve in the lid allows air out of the bag, relieving pressure during compaction. The entire compacted bag is then placed inside the Orbiter trash stowage compartment through an 8-in. diameter opening in the middeck floor. This compartment, known as Volume F, normally is used for wet trash stowage.

This design has been tested and certified using a variety of items including food, water, flight trash, plastic and metal food containers, and teleprinter pages.

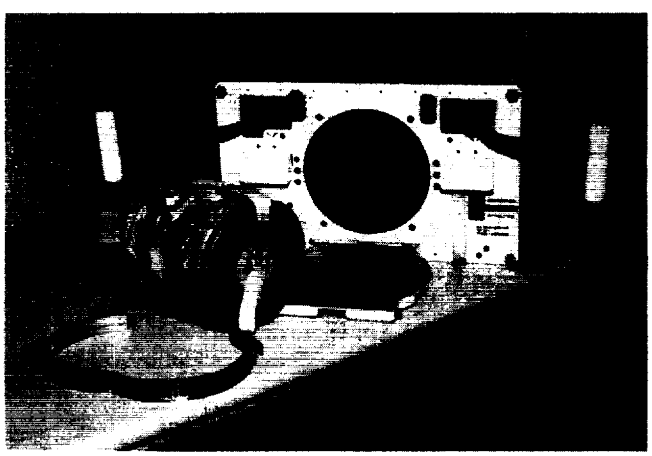


Figure 1. The trash compactor mounted in the middeck locker, showing compacted trash ready for stowage.

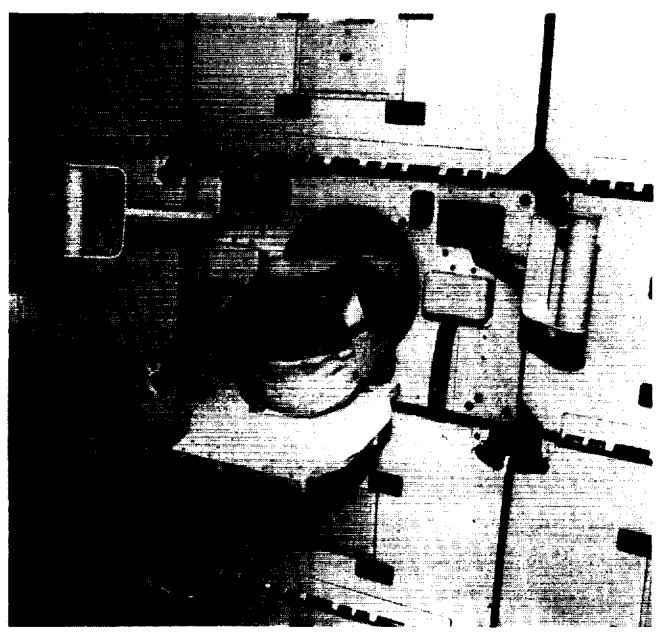


Figure 2. The trash compactor is operated by squeezing the handles towards each other, driving a piston to compact the trash, which is shown after compaction.

Development of the Animal Enclosure Module

PI: **Neil Christie/SP33**
Reference: **HST 10**

The Shuttle Student Involvement Project (SSIP) is a NASA educational program designed to stimulate interest among secondary school students in the subjects of science and engineering by giving them an opportunity to fly their scientific experiments on board the Space Shuttle. The program is a partnership among Government, industrial, and academic disciplines. Student winners of a national competition, conducted by the National Science Teachers Association, are paired with corporate sponsors who finance the building of the students' flight hardware and the operational logistics, such as travel to Johnson Space Center (JSC) safety reviews and the Shuttle launch.

General Dynamics (GD) and Pfizer Pharmaceutical Co. teamed to sponsor Danial Webbers' experiment to investigate zero-g effects on arthritis. The experiment, involving the use of laboratory white rats, posed serious design problems in that the students are allowed only one middeck locker space. Many problems of crew and animal safety and comfort needed to be solved. Another hurdle was the previously unheard of idea of animals on board the Space Shuttle.

A young GD engineer designed the animal enclosure module (AEM)(fig. 1), which was approved for spaceflight after it proved itself in rigorous testing at JSC. The AEM was first flown as a detailed test objective on STS-8. This operational hardware test carried six healthy laboratory white rats. The test was an unqualified success and marked the first time that the crew shared an atmosphere in space with animals.

The student experiment, "Effects of Zero Gravity on Arthritis," was flown on STS 41-B and carried three healthy and three diseased white rats; again, the AEM showed itself to be a remarkably simple and trouble-free solution to what initially appeared to be a very difficult problem.

Other laboratory animals later flew in Space Lab Module on board STS 51-B, in the much larger and more complex research animal holding facility (RAHF). This unit experienced significant in-flight difficulties. The RAHF experience prompted the NASA/Ames Research Facility to build several copies of the original student experiment, AEM, for follow-on animal tests that could be easily manifested on virtually any Shuttle flight.

The original GD AEM was used for a third time on STS-29 to fly an experiment proposed by Andew Fras and sponsored by the Orthopaedic Hospital at the University of California, Los Angeles. Andrew's experiment was to investigate the healing of bone in zero g. This experiment opened a new chapter in medical research with regard to the effects of spaceflight on physiological processes, an understanding of which is essential in the planning of long-term space missions on Space Station, lunar bases, and Mars missions. Two NASA-built AEMs carried eight white rats on board STS-41 and nine animals on board STS-40. The SSIP-developed AEMs allow easy Space Shuttle access for zero-g medical research using small animal models. These devices are now available to serve the needs of Government, industrial, and academic institutions for the conduct of physiological and pharmaceutical studies.

The AEM, a good example of highly specialized equipment developed by the Man-Systems Division at JSC, enhances the usefulness and capability of the Space Shuttle.

The original AEM is now on display at the Kansas Cosmosphere and Space Museum where it continues to be of value in educational programs including student groups, teacher in-services, and space camp lectures.

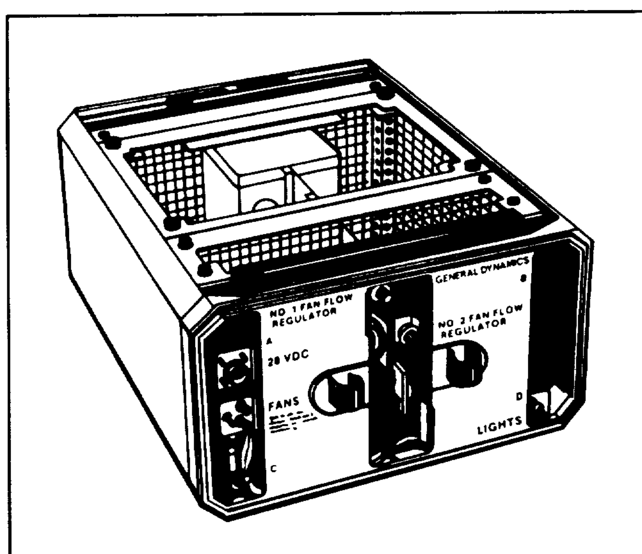


Figure 1. Animal enclosure module.

Shuttle Extended Duration Orbiter Beverage Package

PI: **Charles T. Bourland, Ph.D./SP44**
Vickie L. Kloeris/SP44
Michael F. Fohey/LESC
John F. Marcucci/LESC
Reference: **HST 11**

The extended duration Orbiter (EDO) missions planned for the Shuttle placed new emphasis on reduction in weight and volume of the food system and the associated trash volume. The Shuttle beverage package was identified as a potential source of reduction in weight and volume for both the launch and the generated food trash. Although the original rigid beverage container, with a flexible lid, was nested when stowed for launch and for the trash container, the stowage was still inefficient, and it could not be compacted due to the memory of the rigid polyethylene container. Shuttle EDO missions will have a trash compactor.

An improved Shuttle beverage pouch was developed to replace the rigid base container on EDO missions (fig. 1). The new container was evaluated on routine Shuttle flights and found to be so advantageous that it has now replaced all of the original beverage containers for all Shuttle missions.

The new Shuttle beverage pouch is fabricated from a foil laminate that provides better barrier properties and increases the shelf life of the beverages. A septum adapter was designed to contain the septum, which was the part of the original package that allows the addition of water and serves as a one-way valve to prevent fluid from exiting—except when a straw is inserted. The foil package requires less storage space and weight for launch and can be compacted with the trash. On a typical Shuttle mission of 7 days with a crew of 7, the new beverage pouch saves one locker tray of volume, or approximately 1 ft^3. On a Shuttle EDO mission of 16 days with a crew of 7, the savings increases to 2.2 ft^3.

The volume savings for food-generated trash is even more dramatic. By changing the packaging material to one that is compactable, the volume of food-generated trash is reduced by 75%. Food-generated trash accounts for 70 to 90% of the onboard Orbiter trash. The beverage pouch weighs 11.3 g compared to 25.6 g for the original container, a weight savings of 13.7 kg (30 lb) for a 16-day Shuttle EDO mission.

A new galley adapter device was required for the new beverage pouch to interface with the existing galley (fig. 2). The galley adapter device snaps in place on the rehydration station of the galley, and beverage rehydration occurs in the same manner as in the original package.

The new beverage pouch is presently a strong candidate for use on the Space Station, and a follow-on development is under way to convert the food rehydratable package to a compactable container.

Figure 1. New Shuttle beverage pouch, unrehydrated in the foreground and rehydrated in the background. Koozies are used as insulators.

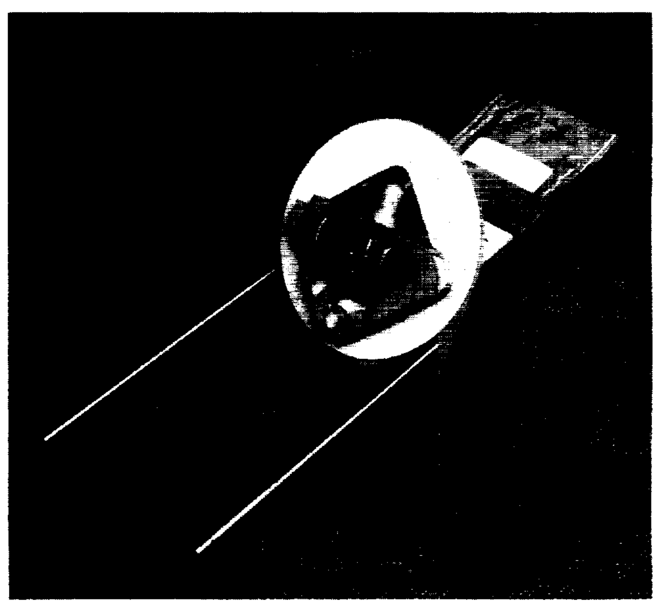


Figure 2. Galley rehydration adapter with beverage pouch inserted.

Head Tracking Versus Manual Input for Camera Control

TM: A. Jay Legendre/SP34
PI: Meera K. Manahan/LESC
Ellen Hwang/LESC
John M. Bierschwale/LESC
Mark A. Stuart, Ph.D./LESC

Reference: HST 12

Telerobotics will play a vital role in the assembly, operation, and maintenance of NASA's Space Station Freedom. Direct views of the worksite will not be available or sufficient for many telerobotic tasks, so cameras will provide the primary mode of visual feedback. Manually controlled camera systems may create difficulty for operators conducting telerobotic tasks that occupy both hands. In such situations, the operator would be required to reorient and readjust his/her hands between the remote manipulator controls and the camera controls. To minimize the reorientation effects, alternative methods of controlling camera functions, such as voice control, eye tracking, and head tracking, are being investigated. Typical camera control functions on Space Station will include pan, tilt, zoom, focus, and iris controls. Allocating some, or all, of the control of the camera viewing system to a head-tracking device may decrease the mental and physical work load on the operator, reduce task completion time, and ultimately improve performance.

This report describes a preliminary investigation of the use of a head-tracking system to control camera views during performance of a remote manipulation task (fig. 1). The objectives of this study were (1) to compare the effectiveness of a prototype head-tracking device to a manually operated joystick for controlling camera pan and tilt functions, and (2) to identify issues affecting implementation of head-tracking devices for telerobotic applications.

Eight test subjects having no prior experience with the use of head-tracking devices performed an inspection task in which panning and tilting of camera views were necessary. All subjects performed the task with a prototype head-tracking device and with a manually operated joystick at the Remote Operator Interaction Laboratory at NASA/Johnson Space Center. Performance and subjective data were collected from each test subject.

The first objective was to compare the effectiveness of a prototype head-tracking device to a manually operated joystick for controlling the camera. Analysis of trial completion times and number of pan/tilt inputs showed that there was no significant difference between the head tracker and joystick for coarse positioning inputs. However, fine positioning movements could be controlled more precisely with the joystick than with the head tracker.

The second objective was to identify issues affecting implementation of head-tracking devices for telerobotic applications using the data gathered during testing. The following set of guidelines was formulated: the head tracker must operate at variable speeds; the deadband of the head tracker (or the area in which head movements do not result in an input) must be adjustable for each operator; and inadvertent commands from the head tracker must be minimized.

Figure 1. Photograph depicting the use of head-tracker camera control device.

Multiple Remote Systems

TM: A. Jay Legendre/SP34
PI: Mark A. Stuart, Ph.D./LESC
Terry F. Fleming/LESC
Reference: HST 13

Many different remotely operated systems will be utilized during lunar/Mars explorations. These remotely operated systems will often be simultaneously controlled and/or monitored. Different systems may be required to work in close proximity to each other at the worksite. Remote operator workstations may also be located adjacent to each other. Studies need to be conducted evaluating issues such as the number of operators required per workstation, information needs of operators, task coordination between the different remotely operated systems, and function allocation analyses between the different remotely operated systems.

The Remote Operator Interaction Laboratory (ROIL) has reviewed Shuttle, Space Station Freedom, nuclear, and subsea operational scenarios involving multiple remotely operated systems. From the evaluation of these scenarios, the ROIL performed feasibility studies and prepared a test plan involving the coordinated use of a large, crane-like manipulator and a smaller dexterous manipulator to take place in FY92 in the Manipulator Development Facility (MDF) at the NASA/Johnson Space Center (fig. 1). Two different operational scenarios will be investigated: (1) remote manipulator system (RMS) and replica systems controlled in parallel by two different operators, and (2) RMS and replica systems controlled serially by one operator.

The replica system will be a Remotec RM10A system. This system consists of two slave arms, replica controllers, electronic cabling, and the control console. The replica controllers and the control console will be located in the aft flight deck area of the MDF. The Remotec slave system will have a grapple fixture attached so that it can be held by the RMS. The RMS model in the MDF does not have the ability to lift the weight of the Remotec, so the Remotec will also be supported by a crane. Figure 2 depicts the counterbalancing scheme for the Remotec and the overhead crane developed by the ROIL.

Operator(s) will be required to be familiar with RMS and Remotec controls, displays, and procedures. At the beginning of sessions in the MDF, operators will be familiarized with the task scenarios, workstation layout, camera views, and questionnaires. Any task involving manipulation of the Remotec arms was carefully preplanned to minimize the center of gravity (CG) travel of the Remotec system. If the CG travel is too large, the MDF/Remotec system stability could be compromised. The different scenarios will be compared in terms of the task performance (completion time, accuracy, and satisfaction of task objectives) and subjective issues. Operators will also be videotaped for later analysis of process information.

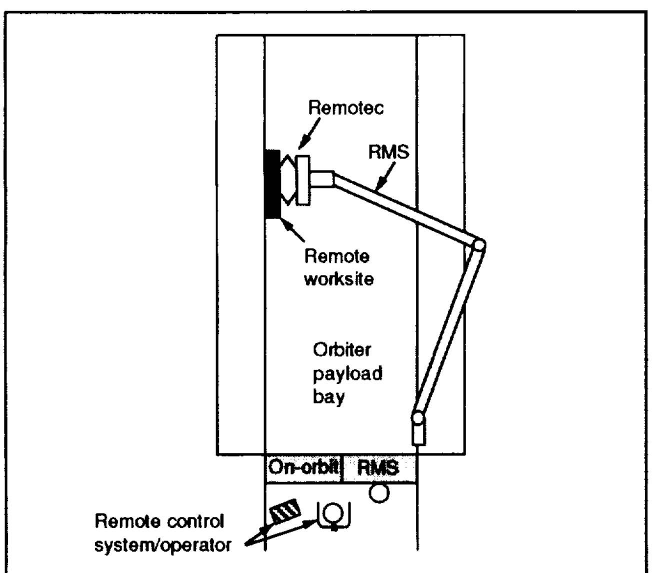


Figure 1. Test setup in the MDF.

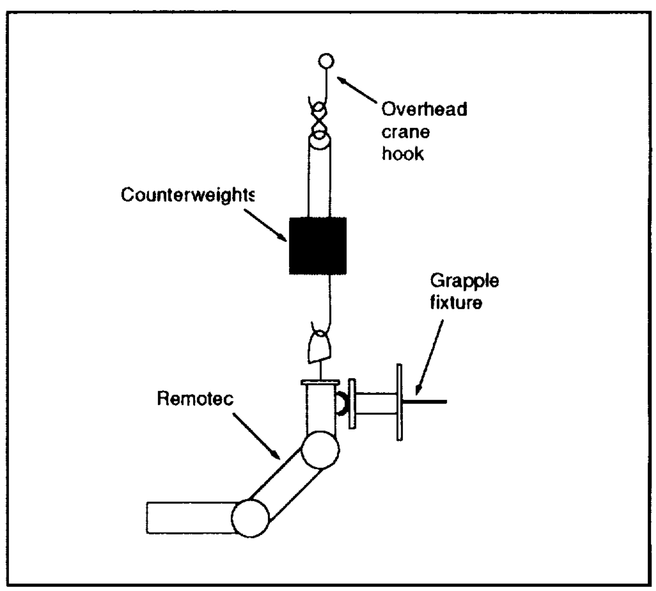


Figure 2. Remotec/crane counterbalancing scheme.

Evaluation of the Orbital Replaceable Unit Alignment Target System

TM:	**A. Jay Legendre/SP34**
PI:	**Carlos E. Sampaio/LESC**
	Ellen Hwang Snook/LESC
	Terry F. Fleming/LESC
	Mark A. Stuart, Ph.D./LESC
Reference:	**HST 14**

Orbital replaceable units (ORUs) will be used extensively on Space Station Freedom (SSF). As a result, there is a strong desire to standardize the design and interfaces of this external equipment to enhance compatibility between crew extravehicular activity and telerobotic operations. In response to this, an interface design review committee was formed consisting of the SSF Program Work Packages, the international partners, and NASA Level II. This committee was assembled to establish appropriate interface design standards to be published in the Robotic Systems Integration Standards (RSIS) document. The interface package from Spar Aerospace was selected for ORUs of 1200 lb or less and consisted of several components, among them an alignment target and electronic overlay concept (fig. 1).

A part of the Man-Systems Division at the Johnson Space Center, the Remote Operator Interaction Laboratory's (ROIL's) expertise lies in its man-systems or user's perspective. ROIL personnel felt that in the ORU grapple task, the alignment target had the greatest operational impact from a human factors perspective. As a result, the ROIL undertook the task of evaluating and refining the Spar alignment target concept. The initial evaluation of this concept showed several operational deficiencies with the Spar target.

Because of these deficiencies, the ROIL began developing alternative target concepts intended to relieve these problems. In internal evaluations of these alternative designs, several proved to be operationally more acceptable than the Spar target design. A formal investigation using participants experienced in space-based remote manipulation was then performed in the ROIL to assess these findings. This investigation also allowed the ROIL to evaluate alternative designs to the electronic overlay associated with the target.

The data from the formal evaluation confirmed the findings of the original engineering evaluation. The Spar target was considered to be unacceptable by the evaluation participants, while the alternative designs were deemed to be a considerable improvement on the concept. Likewise, an alternative design to the electronic overlay resulted in more favorable reactions than the original overlay design.

From these results, recommendations were formulated that will be included in the next version of the RSIS document. The recommended target (fig. 2) is a design selected because it resolved the operational problems encountered with the original Spar design. The deficiencies were resolved without making major modifications to the original Spar concept, thus stressing the importance of even subtle interactions between features of the target.

Also shown in figure 2 is the recommended overlay. It varies from the current concept primarily in that it provides a legal X-axis capture range to the operator when attempting to resolve the final misalignments. The Spar overlay design provided only an absolute X-axis point for legal capture.

This type of work will continue in the ROIL with the intent of providing the SSF Program and future programs with the data necessary to make informed and knowledgeable decisions regarding these and other interface issues.

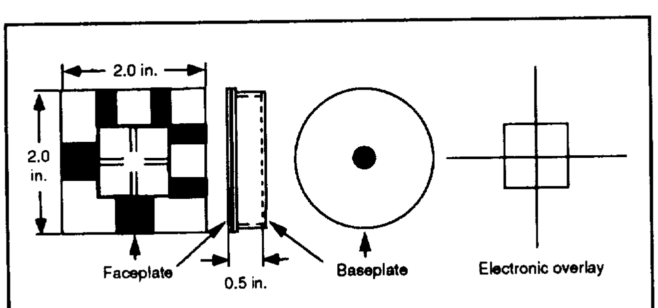


Figure 1. The Spar Aerospace alignment target faceplate, baseplate, and electronic overlay concepts.

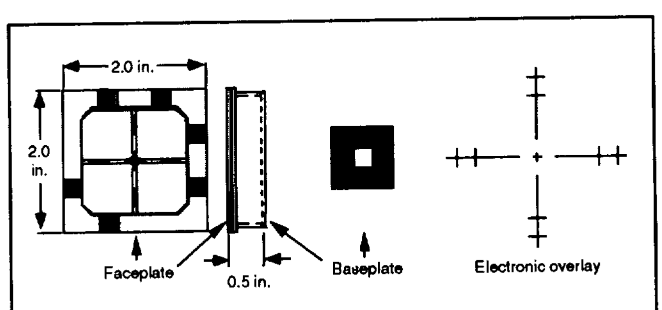


Figure 2. The final ROIL recommended faceplate, baseplate, and electronic overlay concepts.

Camera Placement Effects on Remote Manipulation Performance Using Rate and Position Control Modes

TM: A. Jay Legendre/SP34
PI: Meera K. Manahan/LESC
Ellen Hwang/LESC
John M. Bierschwale/LESC
Mark A. Stuart, Ph.D./LESC
Reference: HST 15

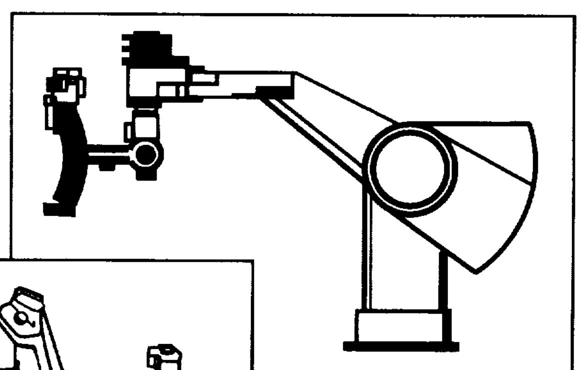
Several studies have been performed to determine the effects on computer-simulated and direct-manipulation task performance when the viewing conditions are spatially displaced. Whether results from these studies can be directly applied to the remote manipulation tasks to be performed on various space platforms is questionable. Studies examining effects of displaced views on remote manipulation were previously conducted in the Remote Operator Interaction Laboratory at NASA/Johnson Space Center using a minimaster hand controller. Since the completion of these studies, a 2-by-3 degree-of-freedom (DOF) orthogonal rate mode hand controller was baselined for Space Station Freedom (fig. 1). The experiment reported in this paper augmented the previously mentioned perturbed feedback remote manipulation evaluations, to include the 2-by-3 DOF hand controller configuration. It was hypothesized that performance using perturbed, or spatially displaced, viewing conditions would vary between the orthogonal and the replica hand controller, and that strategies for task performance may also differ. The objectives of this evaluation were to determine the effects of reversed, inverted, and inverted/reversed views on remote manipulation task performance with a 2-by-3 DOF hand controller; to compare the effects of spatially displaced views on remote manipulation with a 2-by-3 DOF hand controller and a minimaster hand controller (fig. 2); and to compare the minimaster results to a previous perturbed feedback evaluation by Stuart, Bierschwale, Sampaio, and Legendre (1990).

Results showed that trials using the inverted viewing condition showed the worst performance, followed by the inverted/reversed view, and the reversed view when using the 2-by-3 DOF hand controller. However, these differences were not statistically significant. The inverted and inverted/reversed viewing conditions were significantly worse than the normal and reversed viewing conditions when using the minimaster.

The results of the study by Stuart et al. (1990) had shown that the normal view was significantly better than the perturbed viewing conditions. The results from this study showed that the task completion times for the normal and reversed views were significantly faster than completion times for the inverted and inverted/reversed views, with no difference between the normal and reversed views. This variation in results, when compared to the study by Stuart et al. (1990) may have occurred because the task board and the manipulator were visible to a greater extent in this study.

After analyzing the results of the evaluation described above, it was decided that the long-term learning effects between the two hand controllers needed to be measured. A second evaluation was conducted in which three different subjects performed six trials with each of the viewing conditions. The objective of the second evaluation was to determine the effects of successive trials on task performance with spatially displaced feedback across both hand controllers.

Results of the second evaluation showed that the learning curves for the perturbed viewing conditions using the 2-by-3 DOF hand controller were stabilized by the fourth trial and remained constant through the six trials. Learning for the inverted and inverted/reversed viewing conditions using the minimaster was erratic throughout all six trials of the task. However, the reversed viewing condition stabilized. Results indicated that there was more of a difference in performance between the perturbed viewing conditions and the normal viewing condition with the minimaster. This difference was less apparent with the 2-by-3 DOF.



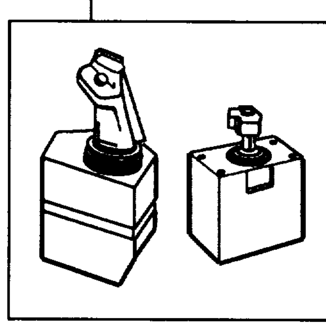


Figure 1. 2-by-3 DOF rate control. (Left)

Figure 2. Minimaster position control. (Above)

Preliminary Evaluation of Partially Constrained Motion Tasks Using 2-by-3 Degree-of-Freedom Hand Controllers

TM: A. Jay Legendre/SP34
PI: Terry F. Fleming/LESC
Carlos E. Sampalo/LESC
Reference: HST 16

As a result of the Space Station Hand Controller Commonality Evaluation completed in late 1990, the 2-by-3 degree-of-freedom (DOF) hand controllers were decreed the program baseline hand controllers. Nevertheless, certain groups feel that a 6-DOF hand controller, with manipulator forces and torques reflected back into the hand controller, is still required for partially constrained motion tasks. One such task is the opening/closing of a hinged door. Although there are many methods of performing this task with 2-by-3 DOF hand controllers, personnel at the Remote Operator Interaction Laboratory (ROIL) at the Johnson Space Center decided to evaluate two methods that did not involve force reflection into the hand controllers or manipulator arm compliance.

The first method developed and evaluated by the ROIL involved displacing the manipulator point of resolution (POR). The POR of a manipulator—typically located between the grippers of a manipulator end effector—is the point in space about which the manipulator movements rotate and translate. By moving the POR via a software change to the hinge point of the task, an operator can perform the task by making a single input into the hand controller; the manipulator will then rotate about the displaced POR. This approach is shown in figure 1.

Work performed in the ROIL has demonstrated this technique. A door with a grapple fixture 15 in. from the hinge was fixed to a stand in the ROIL. By placing the POR 15 in. from the grapple point and at the door hinge, an operator is capable of performing the task by simply commanding a roll input with the rotational hand controller. The POR could be displaced any distance translationally and at any angular orientation. Therefore, the POR could be positioned to suit any grapple point of such a "hinge door task."

In the second method, using a force/torque visual display, ROIL personnel demonstrated that this task could also be successfully performed without moving the POR from its typical position between the grippers of the manipulator. By providing the operator with a visual display of the forces and torques from the manipulator end effector, the operator can effectively perform the task by continually zeroing out the off-axes forces and torques as the arc of the motion is followed. In fact, this method can be used with any POR as long as the PORs for the manipulator control system and the force/torque sensor are in the same position and orientation. The force/torque display developed for use in the ROIL is depicted in figure 2.

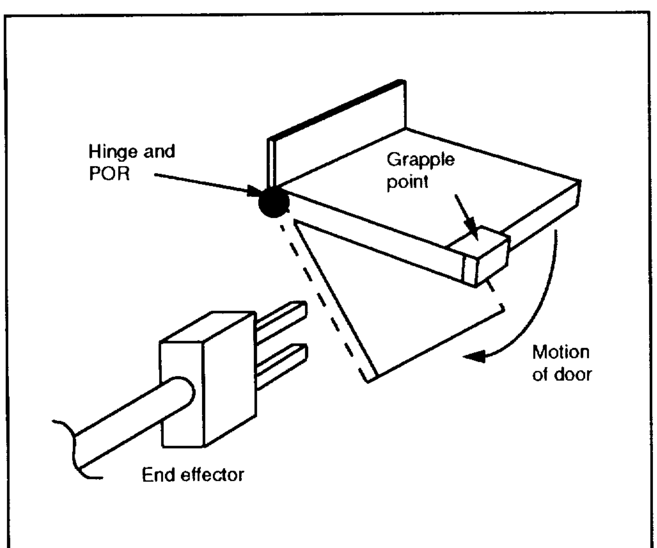


Figure 1. Manipulator end effector and hinged door, with motion of door indicated by arrow.

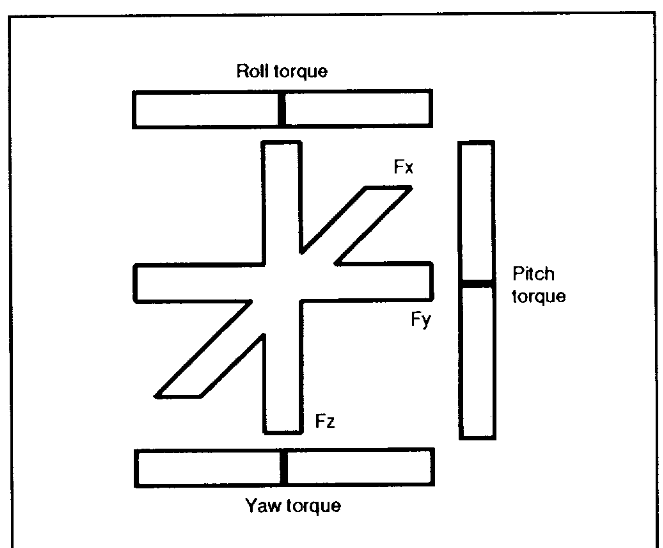


Figure 2. Force/torque visual display.

Evaluation of Prototype Force-Torque Displays

TM: A. Jay Legendre/SP34
PI: Robert C. Hendrich/LESC
John M. Bierschwale/LESC
Mark A. Stuart, Ph.D./LESC
Reference: HST 17

Recent experiments (NASA/Johnson Space Center, 1991) that addressed Space Station remote manipulation tasks have found that tactile force feedback (reflecting forces and torques encountered at the end effector through the manipulator hand controller) does not significantly improve performance. However, subjective responses from astronaut and non-astronaut test subjects indicated that force information, provided visually, could be useful. Little research exists that specifically investigates various methods of presenting force-torque information visually. This experiment was designed to evaluate seven different visual force-torque displays that were found in a survey of universities, industry, and NASA centers. The displays (fig. 1) were prototyped in the HyperCard programming environment. In a within-subjects experiment, seven subjects zeroed out forces and torques presented statically, using a mouse cursor-control device and software-generated response buttons located on the screen below the display. Dependent measures included questionnaire data, errors, and response time.

Subjective data generally demonstrated that subjects rated variations of pseudo-perspective displays (displays 1 through 5) consistently better than bar graph and digital displays. Subjects commented that the bar graph (display 6) and digital (display 7) displays could be used, but were not compatible with using hand controllers. Quantitative data show similar trends to the subjective data, except that the bar graph and digital displays both provided good performance, perhaps due to the mapping of response buttons to display elements. Results indicate that for this set of seven displays, the pseudo-perspective displays generally represent a more intuitive format for presenting force-torque information, although display 5 was not one of the top candidates. The remaining four displays (displays 1 through 4) will be evaluated in a second experiment using an actual manipulator, rotational and translational hand controllers, and a Space Station task.

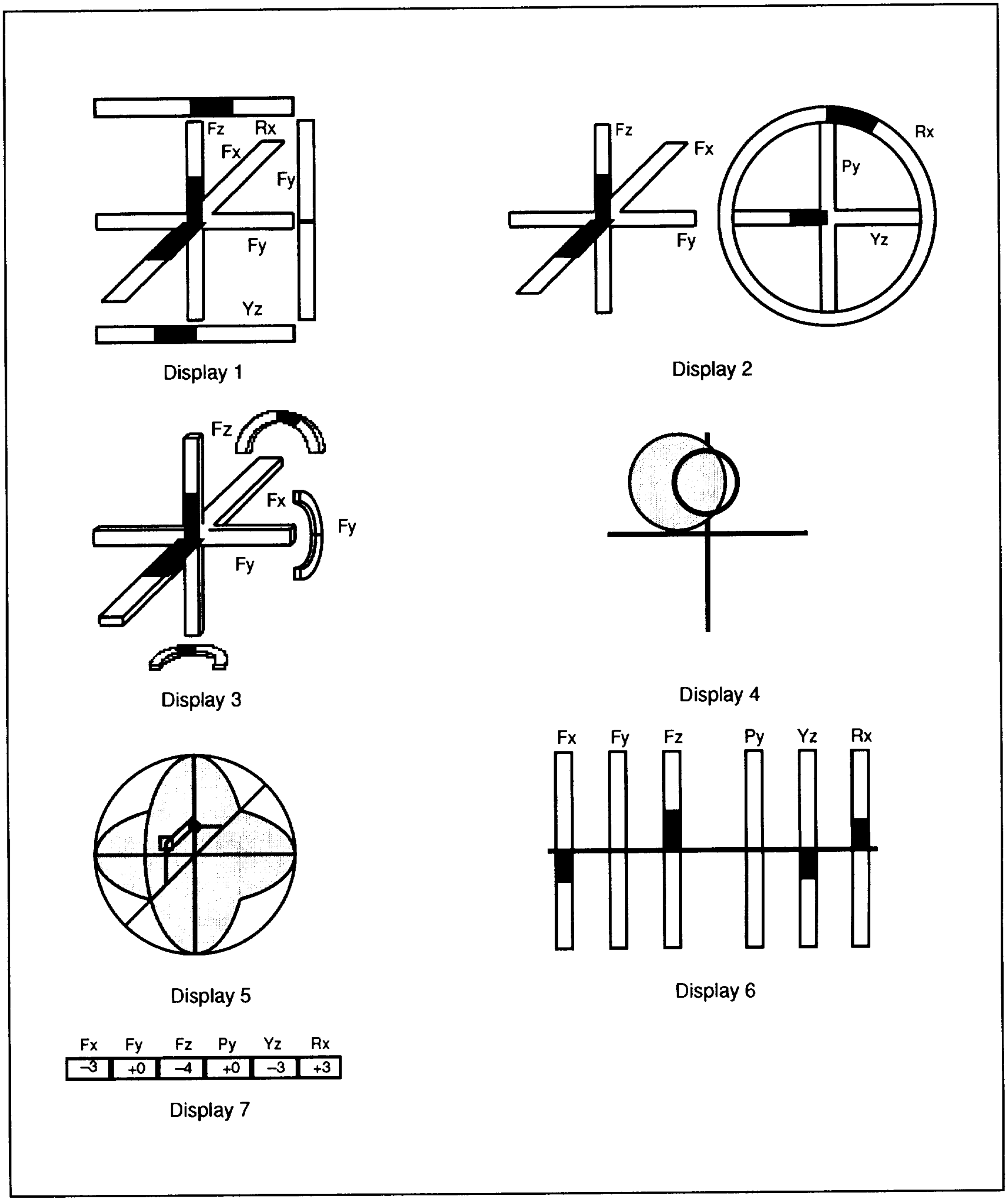


Figure 1. The seven displays investigated, each configured with equivalent forces in X, Z, yaw, and roll.

Astronaut Science Advisor Human-Computer Interface

TM: **Marianne Rudisill, Ph.D./SP34**
PI: **Jurine A. Adolf/LESC**
Kritina L. Holden, Ph.D./LESC
Reference: **HST 18**

While conducting experiments on orbit during Shuttle missions, astronauts need to communicate with the principal investigator (PI) on the ground to handle anomalies with scheduling, data collection, and equipment failures. It would be best to communicate with the PI directly and immediately as the problem evolves. However, due to problems of loss of signal and competition for communication resources, this is not always a viable option. In addition, having the PI available on demand is very difficult and will become more difficult as mission durations increase (e.g., on Space Station Freedom). To explore approaches to alleviate some of these problems, an expert system called the Astronaut Science Advisor (ASA), also known as "PI-in-a-Box," was developed as a joint venture with the Massachussetts Institute of Technology, NASA/Ames Research Center, and the Human-Computer Interaction Laboratory (HCIL) at Johnson Space Center.

A vestibular experiment scheduled for Spacelab Life Sciences missions 1 and 2 (SLS-1, SLS-2) was selected as the initial target experiment for ASA. The expert system will aid the astronaut in three ways: in scheduling, in detecting "interesting" data, and in assisting during troubleshooting hardware problems. The first system module, the Protocol Suggester, suggests adding or deleting experimental runs if the astronaut is ahead or behind of the data collection protocol. The second module compares the current data with baseline ground data and previous flight data to determine the data "interestingness." If this module (called the Interesting Data Filter) detects "interestingness," a new protocol is generated to more fully explore that issue. The last module, the Diagnostic Troubleshooting Module, assists the crew in troubleshooting hardware malfunctions.

The HCIL has been developing the human-computer interface for this flight expert system. All possible scenarios of crew performance of the experiment were task analyzed, and off-nominal situations were then classified. The work focused on creating a rapid prototype of the system crew interface. HyperCard was used for developing this prototype; based on its compatibility with the expert system software, the prototyped interface became the production interface for ASA (figs. 1 and 2). Feedback from members of the Astronaut Office and the flight crew provided information used during iterations in the prototype design.

After conducting a ground test of the system during SLS-1 (June 1991), a great deal was learned about the operational environment surrounding the use of the ASA system. Currently, the team is proposing to fly the ASA on board SLS-2 (1993) as a true flight-based support system to the on-orbit vestibular experiments.

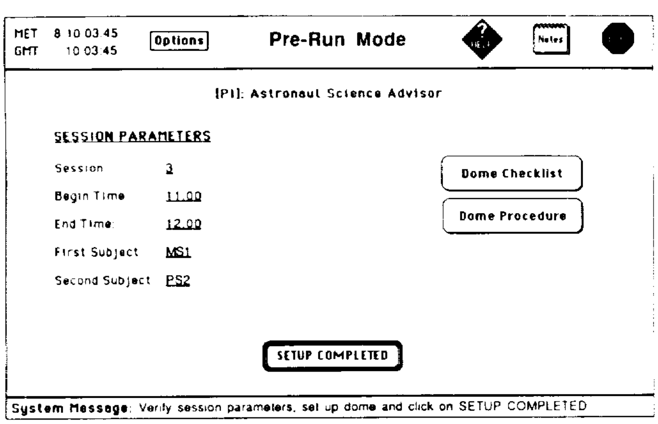


Figure 1. Setup screen.

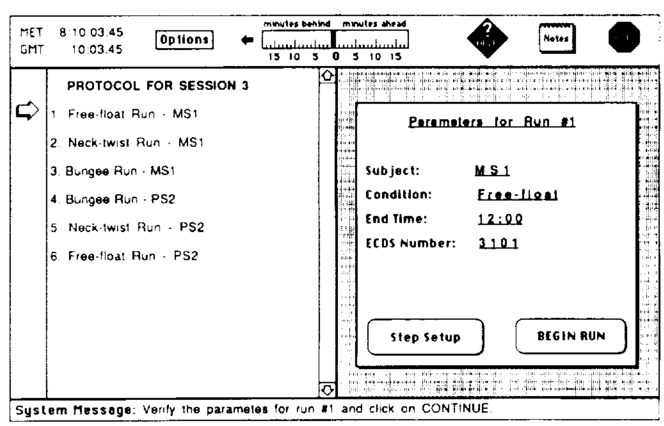


Figure 2. Run-time screen.

Extravehicular Activity Electronic Cuff Checklist Prototype

TM: Marianne Rudisill, Ph.D./SP34
PI: Jurine A. Adolf/LESC
Kritina L. Holden, Ph.D./LESC
Michael R. O'Neal/LESC

Reference: HST 19

Procedure checklists are a very important part of extravehicular activity (EVA) tasks. Whenever astronauts venture outside the controlled cabin environment, information about the task to be performed, suit status, and emergency procedures all must be at the astronaut's fingertips and quickly accessible. This is obviously a challenge in the open space environment. The present solution involves the use of a paper cuff checklist that is strapped onto the EVA crewmember's arm. Due to the bulk of paper, the number of pages (and, therefore, amount of information) is limited.

Recently, the Human-Computer Interaction Laboratory (HCIL) at Johnson Space Center was asked to collaborate with the Crew and Thermal Systems Division on a prototype development effort that addressed some of the above concerns. The project involved the development of an electronic cuff checklist (ECC) for use during EVA. An electronic medium allows capabilities that are not possible with paper versions and, most importantly, increased information access. Crew and Thermal Systems Division personnel developed the hardware prototype and the HCIL designed the human-computer interface (HCI).

One of the greatest challenges was designing the method of interaction. Since gloved hands will be operating the ECC, input methods were very constrained. An intuitive means of accessing menus, toggling between procedure lists, and accessing emergency information with a minimum of user inputs were all challenges that were met through iterative prototyping of the HCI.

The prototype HCI was developed in HyperCard and ultimately written to programmable read-only memory chips for insertion into the hardware unit. As a by-product of the HyperCard stack, a software prototype was developed. Sample screens from the software can be seen in figures 1 and 2. The first figure shows an example of a menu screen with the sextant arrangement of menu items corresponding to the six arrows representing the three toggle switches pressed in up or down positions. The second figure shows a procedure screen with the sextant format located at the bottom of the procedure. The labels located directly above and below the arrows (e.g., STOPWATCH) represent the action of a press and hold of the toggle switch. The content and format of the procedures were taken directly from existing Shuttle hardcopy procedures.

The hardware prototype unit has been completed and is in the testing phase. Thus far, the EVA ECC has been met with a great deal of enthusiasm by both crew and non-crew.

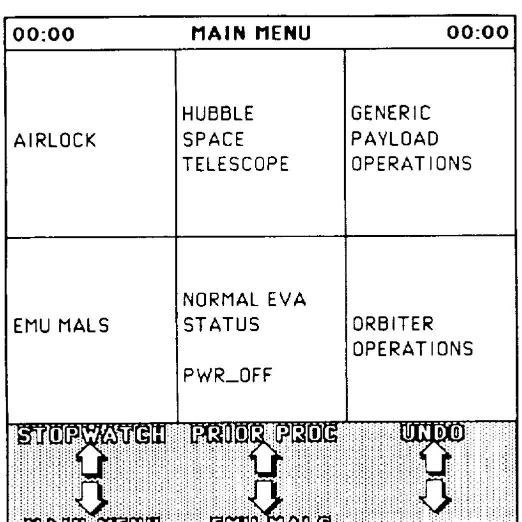


Figure 1. A menu screen example.

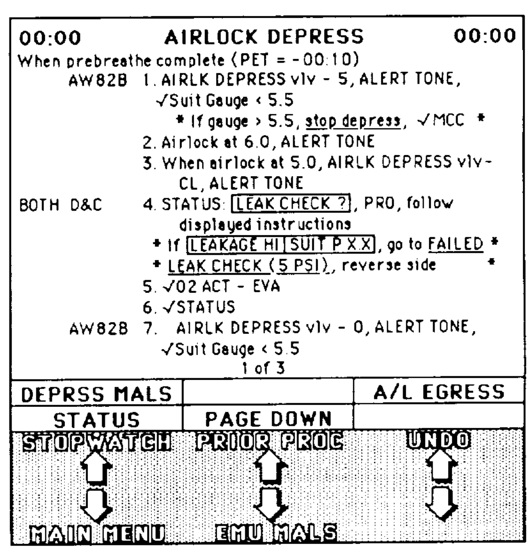


Figure 2. A procedure screen example.

Human-Computer Interface to Medical Decision Support Systems for Space

TM: **Marianne Rudisill, Ph.D./SP34**
PI: **Jurine A. Adolf/LESC**
John Gosbee, M.D./LESC
Reference: **HST 20**

For the longer and more complex missions of Space Station Freedom and the distant missions to the Moon and Mars, more sophisticated health care delivery systems will be needed. Furthermore, crewmembers on the Moon and Mars missions will become increasingly independent of Earth-based support facilities. Because of this increased complexity and independence, reliance on computer-based medical support systems by the crew medical officer and other crewmembers is inevitable.

Computer-based medical decision support systems for use in future space missions will likely include three major parts: (1) a data base of medical textbooks for reference, (2) a "cookbook" of medical procedures to aid in delivery of treatment, and (3) an expert system for diagnosis of illnesses and injuries. For example, the Space Station Freedom Health Maintenance Facility plans to include an integrated medical decision support system, which provides a data base of medical references, medical treatment procedures, and an expert system to assist in diagnosis. The system will be designed to be used by both physicians and non-physicians.

The Human-Computer Interaction Laboratory (HCIL) in the Johnson Space Center Man-Systems Division has begun a research effort to evaluate and improve human-computer interaction between the crewmember and a medical decision support system. Many of the human-computer interaction issues for medical reference systems are being extensively researched by others. The HCIL has completed work on certain aspects of computer-based medical procedures (see below). However, there are many questions about crewmember interaction with medical expert systems that remain to be identified and answered before developing a usable system for space missions.

The computer-based procedures work already conducted includes the use of the cognitive modeling method "GOMS" (Goals, Operators, Methods, and Selection Rules) to design computer-based medical procedure checklists. Two medical procedures (indirect laryngoscopy and electrocardiogram (ECG) setup) were analyzed and two different human-computer interfaces were created: one used the format and organization from the GOMS analysis while the other used the format and organization typically found in medical textbooks (figs. 1 and 2). User performance on the computer-based medical procedures was found to be superior with the GOMS-based interface, and recall of the procedures was "GOMS-like" even with users who had used the linear interface.

To study the human-computer interaction issues in the domain of medical decision support systems, the 3-year plan includes both an initial information-gathering phase to identify human factors issues and laboratory research to systematically investigate those issues identified. To identify the most useful and interesting issues, a variety of activities are planned including: evaluation of existing medical decision support systems, structured interviews with medical personnel, and research in areas of explanation facility capabilities, time-consuming data input, trust and acceptance variables, medical terminology diversity, and decision-making errors.

Setup equipment

(Level 3)

Attach Leads to Patient and to TRAM

* 1. Find electrode sites on patient

2. Prepare the electrode sites

3. Attach new electrodes to patient

4. Wire up the patient to the monitor

5. Use stress loops

Done Reading

Figure 1. Hierarchical, ECG setup procedure.

2.2 Prepare patient both mentally and physically

2.2.1 Explain procedure in detail. Careful counseling as to how the examination is done should help the patient relax. A relaxed, cooperative patient is a prerequisite to adequate visualization of the larynx.

2.2.2 If patient has dentures, remove them

2.3 Prepare mirror

2.3.1 Select most suitable mirror

- Select the number 5 mirror if it will fit comfortably in the back of the mouth. Otherwise, use the number 4 mirror

2.3.2 Warm the mirror in the flame of the alcohol lamp or in the hot water

2.3.3 Check the temperature on the back of the hand

* p. 3

Done Reading

Figure 2. Linear, laryngoscopy procedure.

Human-Computer Interfaces to Intelligent Systems

PI: **Marianne Rudisill, Ph.D./SP34**
Evan Feldman/LESC
Kevin O'Brien, Ph.D./LESC

Reference: **HST 21**

In the area of interfaces to intelligent systems, research is being conducted in the Johnson Space Center Human-Computer Interaction Laboratory (HCIL) to determine factors contributing to collaboration between human operators and automated expert advisors. In work environments where the operator is monitoring the stability of some operating system, automated expert systems are used as advisors and report to the operator an assessment of the system status. The form of the advisor's report can be as simple as an alarm or as complex as an interpretation of the system status and an accompanying estimate of the accuracy of the assessment. Many anecdotes describe operators either ignoring these advisors or responding blindly to them. Research is being conducted in the HCIL to identify those factors that affect the communication and decision-making process in operator-expert advisor work environments (fig. 1), thereby, to be able to better define the requirements for such systems.

Following the work of R. Sorkin (U. of Florida), in which the automated expert advisor is an independent participant in decision making, the decisions of operators regarding system status have been demonstrated to be affected by the amount of information provided by the advisor, the frequency of the advisor's false alarms, and the match between advisor and operator skill levels. Work ongoing in the HCIL has shown that operators are capable of screening out, at least in part, the information provided by a poorly skilled advisor (fig. 2). Studies also demonstrate that the operator is capable of recognizing when the advisor is more highly skilled and incorporating the information of the advisor in those cases. Further studies will examine the operator's ability to combine information and use advice under time pressure, and how the operator comes to know the advisor's skill level.

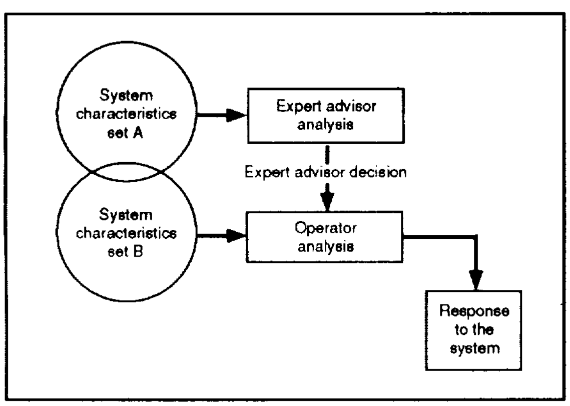


Figure 1. Schematic representation of the expert advisor-aided decision process.

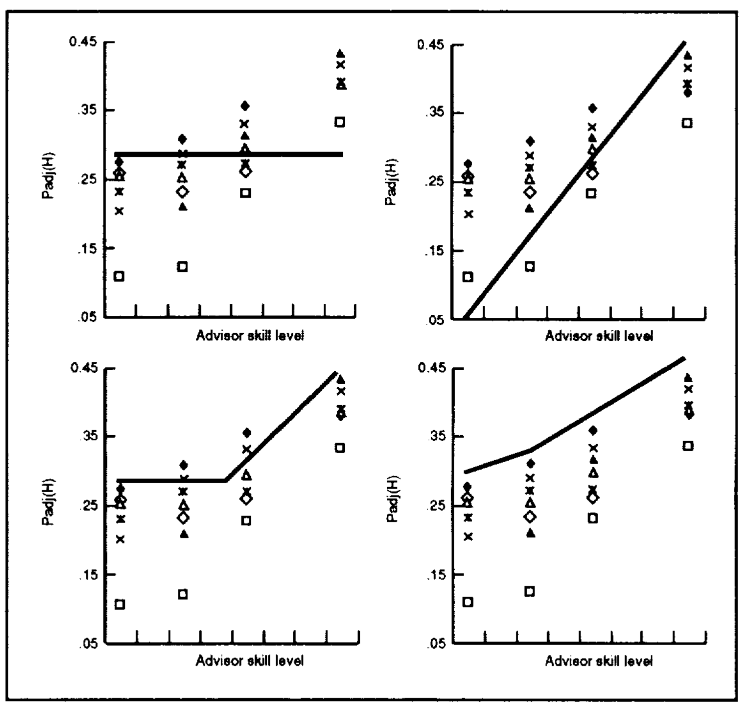


Figure 2. $P_{adj}(H)$ as a function of advisor skill level. The operator-only, advisor-only, selective-operator, and cascade multiple-observer models are presented in the upper-left, upper-right, lower-left, and lower-right positions, respectively. Expected performance is represented by the solid line with subject responses represented by geometric characters.

Display Screen Coding with Color

TM: Marianne Rudisill, Ph.D./SP34

PI: Kevin O'Brien, Ph.D./LESC
Kim Donner/Rice University
Timothy McKay, Ph.D./LESC

Reference: HST 22

Almost any computer interface is a conduit for information. As such, one of the primary responsibilities of any interface developer or researcher is to increase our understanding of how the code, in which the information is presented, communicates content to the user. In the last year, the Human-Computer Interaction Laboratory (HCIL) has examined two screen-coding issues.

Users are frequently confronted with the task of narrowing their focus to a single item of interest in a display containing many points of information. Highlighting (e.g., blinking, reverse video, varying brightness) the anticipated item of interest is one manner by which the search and focus task can be aided. The research conducted in the HCIL compared the focusing capacity of highlighting to other information coding methods and examined the possibility that highlighting could be added to the parameters Tullis has proposed for defining search for on-screen information. Experimental results (fig. 1) demonstrated that improvements in search performance resulting from good formatting of displays equaled those achieved by highlighting in poorly formatted displays (fig. 2). The findings were presented at the 35th Annual Meeting of the Human Factors Society.

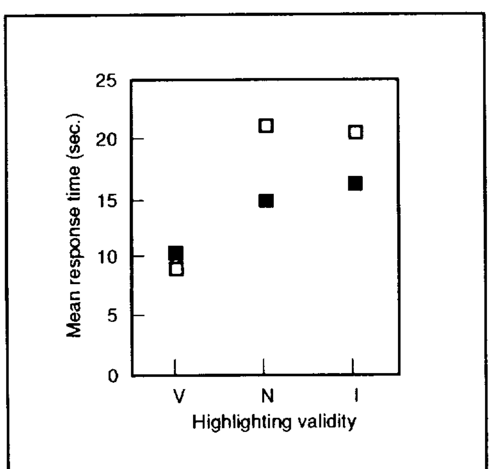


Figure 1. Search performance as a function of highlight validity and displays format.

Coding information with color has often been recommended as a means of improving both search and identification tasks. While the advantages to be gained from adding color to search tasks are fairly well defined, the use of color to aid identification tasks is not well understood. Since an identification task requires the user to correctly associate the information presented on the display with information from memory, the task is heavily dependent on the human capacity for distinguishing and remembering information. The use of color to enhance identification of on-screen information was examined and no benefits of color-coding were found when the task was one involving the overlearned activity of identifying numbers. The findings have been submitted as a NASA report.

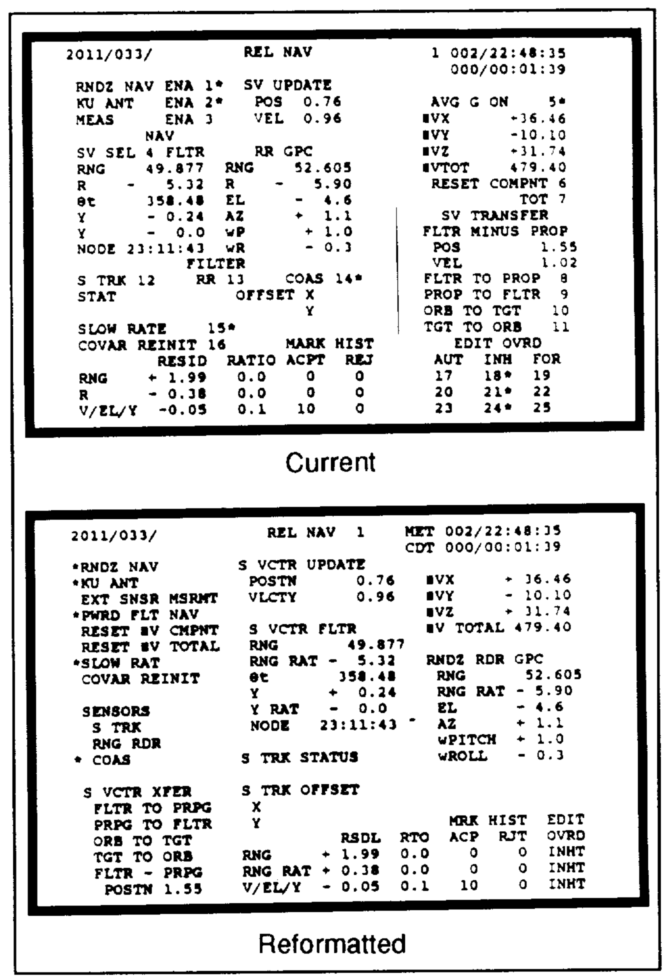


Figure 2. Example of the current (top) and reformatted (bottom) relative navigation experimental displays.

Human-Computer Interface to Geographical Information Systems for Space

TM:	**Marianne Rudisill, Ph.D./SP34**
PI:	**Kevin O'Brien, Ph.D./LESC**
	Benjamin Beberness/LESC
	Steven Chrisnan/LESC
Reference:	**HST 23**

All activities on planetary surfaces involve making decisions about access and resources. These decisions must include information about the location and relative proximity of planetary characteristics of interest to the decision maker. Historically, maps supplied this information. Computer technology has allowed the development of Geographic Information Systems (GISs) that contain information in a spatial format, allow for the manipulation of the information, and provide a means for dynamic maps of the information. While a great deal of work has been done with regard to the application of this technology to Earth issues, its application to supporting decision making for activities on other planets provides new challenges.

Planetary exploration activities operating out of Earth, orbital, and planetary surface bases would all benefit from the depth of information that can be supplied by a GIS. Earth-based decision makers could use the GIS to plan remote satellite passes or select landing sites using a variety of criteria. Orbital observers could use regularly updated GISs to refine landing plans or guide remote vehicles (satellite or ground) to gather comprehensive information regarding specified sites. Surface-based users could use GISs to balance operational constraints with scientific needs in planning activities.

To meet these challenges, the human-computer interface to the GIS must be able to reflect the accuracy of the information presented, support both operations and scientific requirements, and communicate the spatial information so key to the task. The Human-Computer Interaction Laboratory has been reviewing literature on GIS theory and technology, compiling a task analysis of the landing site selection task, and examining current GIS software. A summary of this preliminary work is being prepared. Further work on the GIS interface will focus on gathering information from current GIS users, empirical studies of decision-making performance, and a prototype GIS for planetary use.

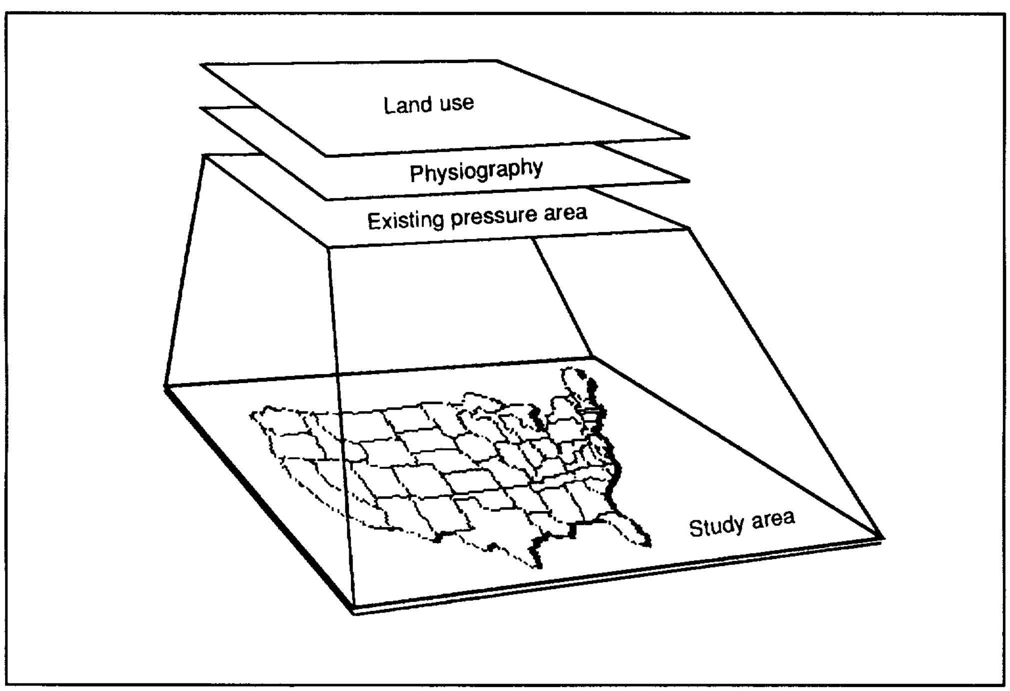


Figure 1. Schematic representing the mapping of multiple characteristics onto geographical space in a GIS.

Space Station Freedom Flight Human-Computer Interface Standards: SSP 30570

PI: **Marianne Rudisill, Ph.D./SP34**
Kritina L. Holden, Ph.D./LESC
Jurine A. Adolf/LESC
Benjamin Beberness/LESC
J. M. Loman/MDSSC
Reference: **HST 24**

In the flight environment, the Space Station Freedom data management system (DMS) will consist of a network of multipurpose application consoles or computer workstations. The DMS will provide all of the computer capabilities, including those capabilities associated with the human-computer interface (HCI). This portion of the DMS software is termed the user support environment (USE). The USE will reflect a direct manipulation environment, which means that crewmembers will command system components by manipulating on-screen representations of those system components. In other words, crewmembers will use a cursor control device (currently baselined as a trackball) to select and command graphical objects representing pumps, valves, and other system structures.

The Space Station Freedom Program Flight Human-Computer Interface Standards (SSFP HCIS) document is a program-applicable standards document for all personnel developing HCIs for the Freedom onboard environment (fig. 1). Commonality among the hundreds of displays with which crew-members will interact is essential for streamlining crew training and ensuring crew productivity and safety. One way of encouraging commonality in interface design is through the use of design standards. These standards place restrictions on the choice of design variables (e.g., color, text style, and graphics), while also providing guidance on more abstract variables such as the conceptual approach and organization of the information.

The HCI consists of: (1) information presented to the user, (2) information input by the user to the system, and (3) the method of interaction between the user and the computer. The HCIS document provides standards for all three of these components of the HCI. In addition to the standard introductory sections, the HCIS is divided into four major sections: (1) a common user interface overview, (2) global HCIS, (3) detailed standards, and (4) several appendices.

The common user interface overview section gives an overview of the display components, methods of interacting with the system, and the conceptual approach to interface design. The global HCIS section provides information about the use of global display components (e.g., text, numbers, and graphics), and gives guidance on information coding (e.g., the use of color, bolding, or bordering). It also provides a description of the methods of interface navigation that are available on board, multiscreen issues, dynamic display outputs, and methods of designing for consistency. The detailed HCIS section includes detailed information about the look and operation of display areas, building blocks, and specialized combinations of building blocks. The appendices contain reference information such as the font and icon libraries, and a reference matrix or "checklist" that contains the individual standards without the supporting descriptions and examples.

Designers of interfaces for Freedom should use the HCIS in conjunction with the Man-Systems Integration Standards (NASA-STD-3000). NASA-STD-3000 contains standards that are high-level and not DMS design dependent. In other words, while the standards in the HCIS are representative of Freedom's onboard computer capabilities, NASA-STD-3000 provides standards for a wide range of capabilities, which may or may not be part of the current DMS design.

The HCIS has been through several technical reviews, including the Space Station Freedom Integrated Systems Preliminary Design Review. All work packages and the international partners have had an opportunity to review the document and submit requests for changes or clarifications. The HCIS is currently in the program baseline cycle and is available for distribution.

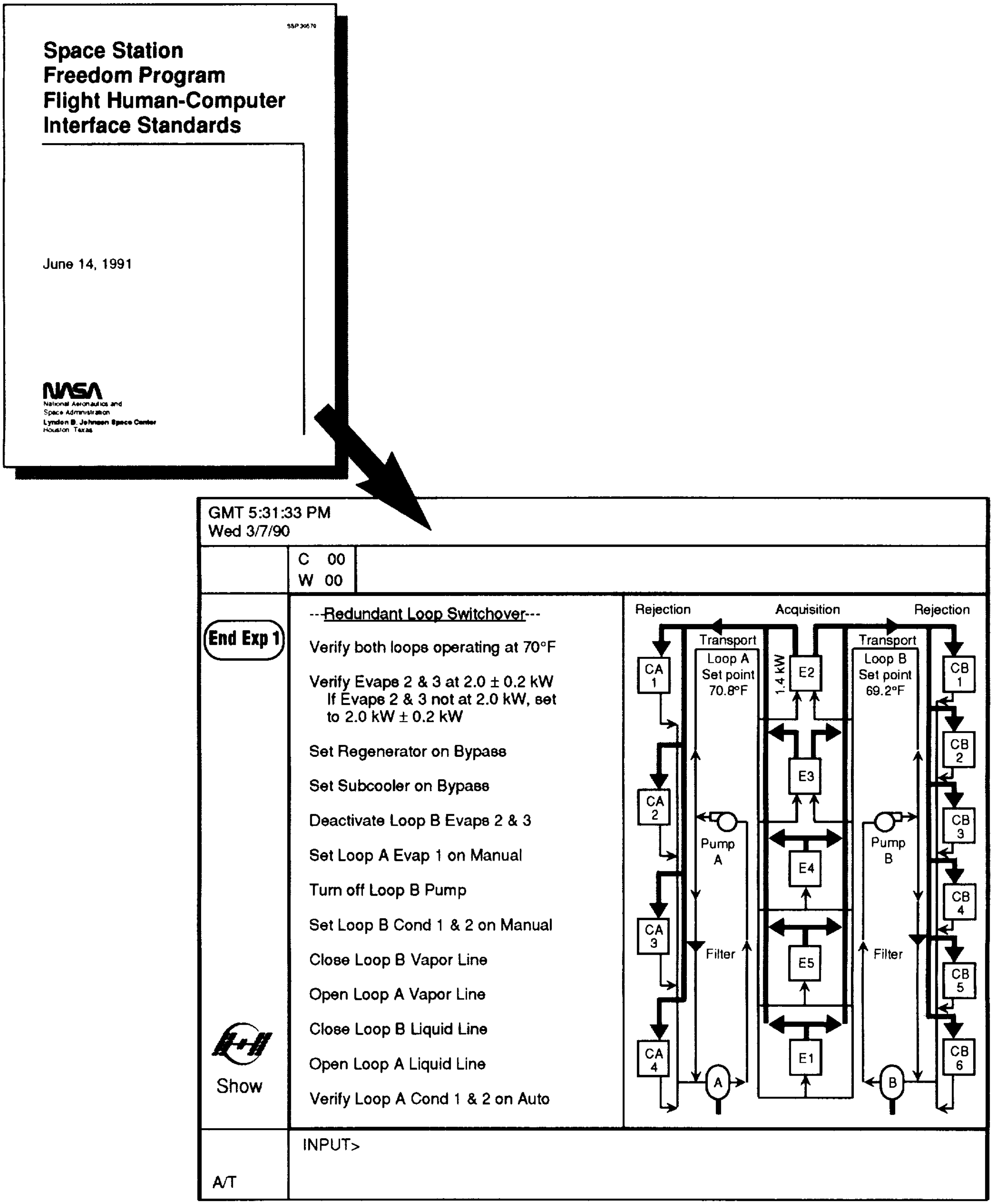


Figure 1. The SSFP HCIS is used by display designers for all displays in the Space Station Freedom flight environment.

Human-Computer Interface to Electronic Procedures Research

PI: **Marianne Rudisill, Ph.D./SP34**
Michael R. O'Neal/LESC
Timothy McKay, Ph.D./LESC
Reference: **HST 25**

Collections of statements that describe the methods to use in performing a task are called *procedures*. The role of computers in the display of onboard spacecraft procedures is increasing. For example, NASA has determined that the operations data file (ODF) procedural system for Space Station Freedom will be computer-based rather than paper-based. The reasons behind this decision include cost savings, faster and more accurate creation and maintenance, individual annotation capabilities, individually customized help, and ease of applying changes.

Research is being performed in the Human-Computer Interaction Laboratory (HCIL) to explore ways to improve the computer interface to electronic procedures. One aspect of the research program involves the creation of functional interface prototypes and their review by human factors, flight crew, mission operations, and other personnel. The program also includes experimental research where specific characteristics of the human-computer interface (HCI) are studied in detail in a controlled environment to determine their effect on human performance with electronic procedure tasks. Results from both prototypes and experiments are used to create HCI guidelines and standards, which are then followed by flight software developers.

A prototype of a Space Station ODF crew procedure has been designed in conjunction with Johnson Space Center Mission Operations Directorate personnel. The prototype demonstrates the electronic interface to the crew task of correcting a "Temperature Out of Range" condition (figs. 1 and 2). Design iterations are currently in progress, along with internal team and flight crew reviews. Further formal reviews of the prototype are being planned. The prototype will reflect both ODF HCI standards and the overall Space Station Flight HCI Standards. Comments received from prototype reviews will lead to further standards refinements and to additional prototypes.

Experimental research has been conducted to explore the effect of procedure format (text or graphic flowchart) on task performance. Current research is exploring which format yields improved performance as the percentage of nonlinear ("IF") statements increases.

The HCIL is continuing prototype development and experimental research projects to study various aspects of the HCI to electronic procedures. As more results are obtained, the HCIL will create a human performance model for the interface to electronic procedures. The model can be used for current and future space programs and in other electronic procedure systems.

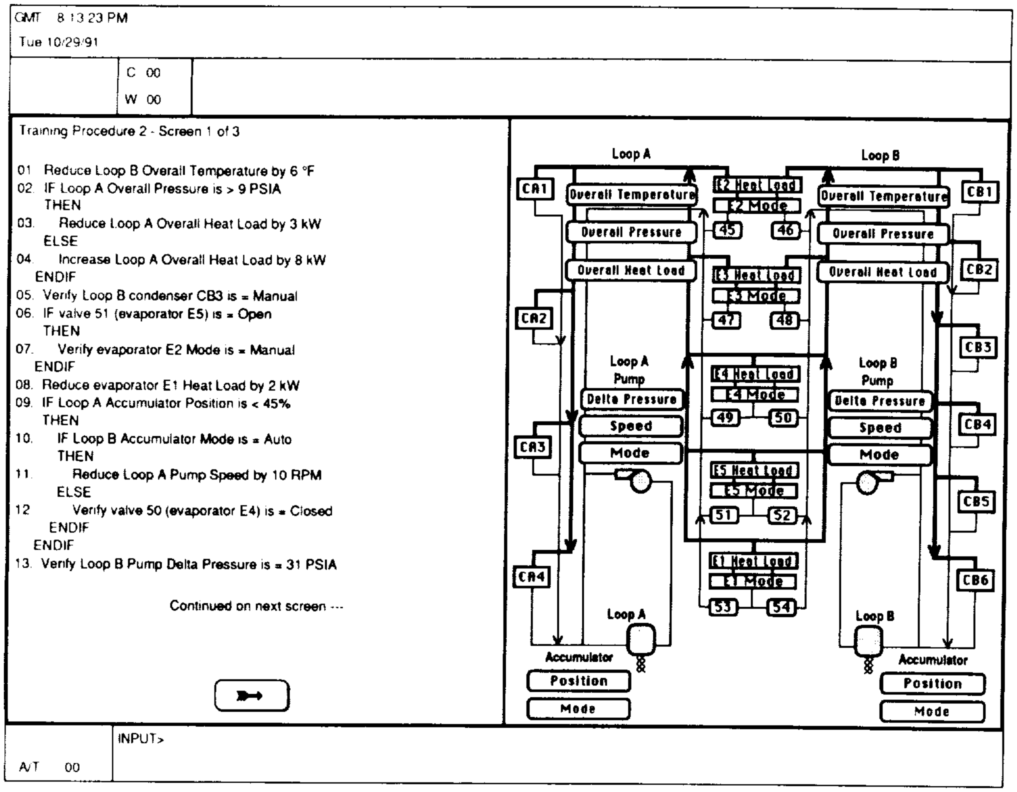


Figure 1. Sample screen from "Temperature Out of Range" prototype showing decision box, connectors, and warning box.

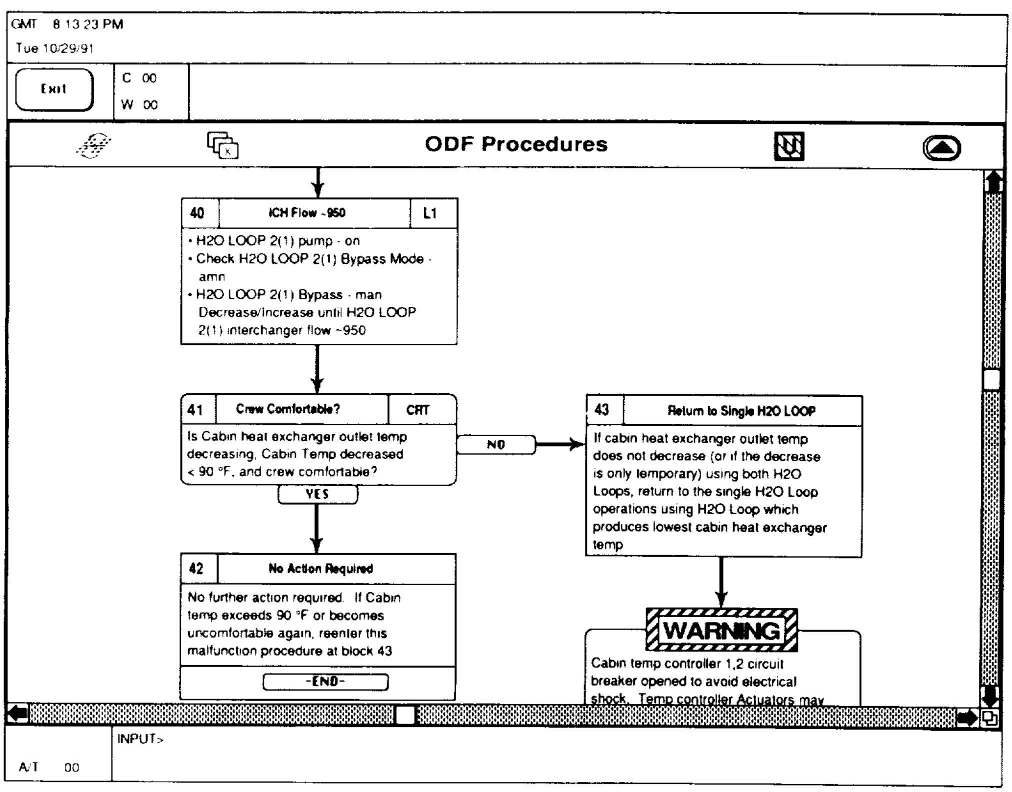


Figure 2. Sample screen from current format experiment showing sample procedure and diagram used to complete procedure steps.

Human-Computer Interface to Multitasking

PI: **Marianne Rudisill, Ph.D./SP34**
Steve Chrisman/LESC
Kritina L. Holden, Ph.D./LESC
Michael R. O'Neal/LESC

Reference: **HST 26**

The Human-Computer Interaction Laboratory (HCIL) is investigating user interaction with computer systems while performing multiple simultaneous tasks, "multitasking." This research centers on the issue of the cognitive load on the user while multitasking and how best to design the human-computer interface (HCI) to minimize this load. The work has focused on two issues. The first issue deals with situations where a crewmember or flight controller is multitasking, is interrupted and must postpone the original task, and then must resume the original task. The operator may or may not choose to act on the interruption, based on knowledge about the events, rules, or some prioritization scheme. The important characteristic of all interruptions is that a current activity must be halted at least long enough to make a decision of whether or not to deal with the interruption. The second issue involves the use of window-management techniques during multitasking (fig. 1).

Interruptions are prevalent in nearly every situation involving a human operator. They are prevalent in space system operations, occur in both ground and flight environments, and range from the mundane to the potentially catastrophic. For example, a typical flight controller will perform two main tasks: (1) monitor real-time data, and (2) check, verify, and modify flight procedures. Interruptions commonly occur when co-flight controllers request system information and when observers (e.g., trainees) request operations information during a mission.

The HCIL is currently compiling a summary paper that describes aspects of interruptions that influence human performance. The paper will suggest methods for the design of the HCI to minimize user workload during multitasking and will describe these factors and use scenarios to illustrate certain topics.

A list of interruption attributes and related factors that have been identified as influencing human performance in interrupted multitasking situations includes

- Similarity of the interruption to the primary task
- Use of warning of impending interruption
- Duration of the interruption
- Amount of information contained in the interruption or interrupted task
- Phase of activity where an interruption occurs
- Prioritization of tasks (in determining how an operator is likely to handle an interruption)
- Use of reminders for the postponed activity
- Interaction of experience and skill level of the operator with interruptions

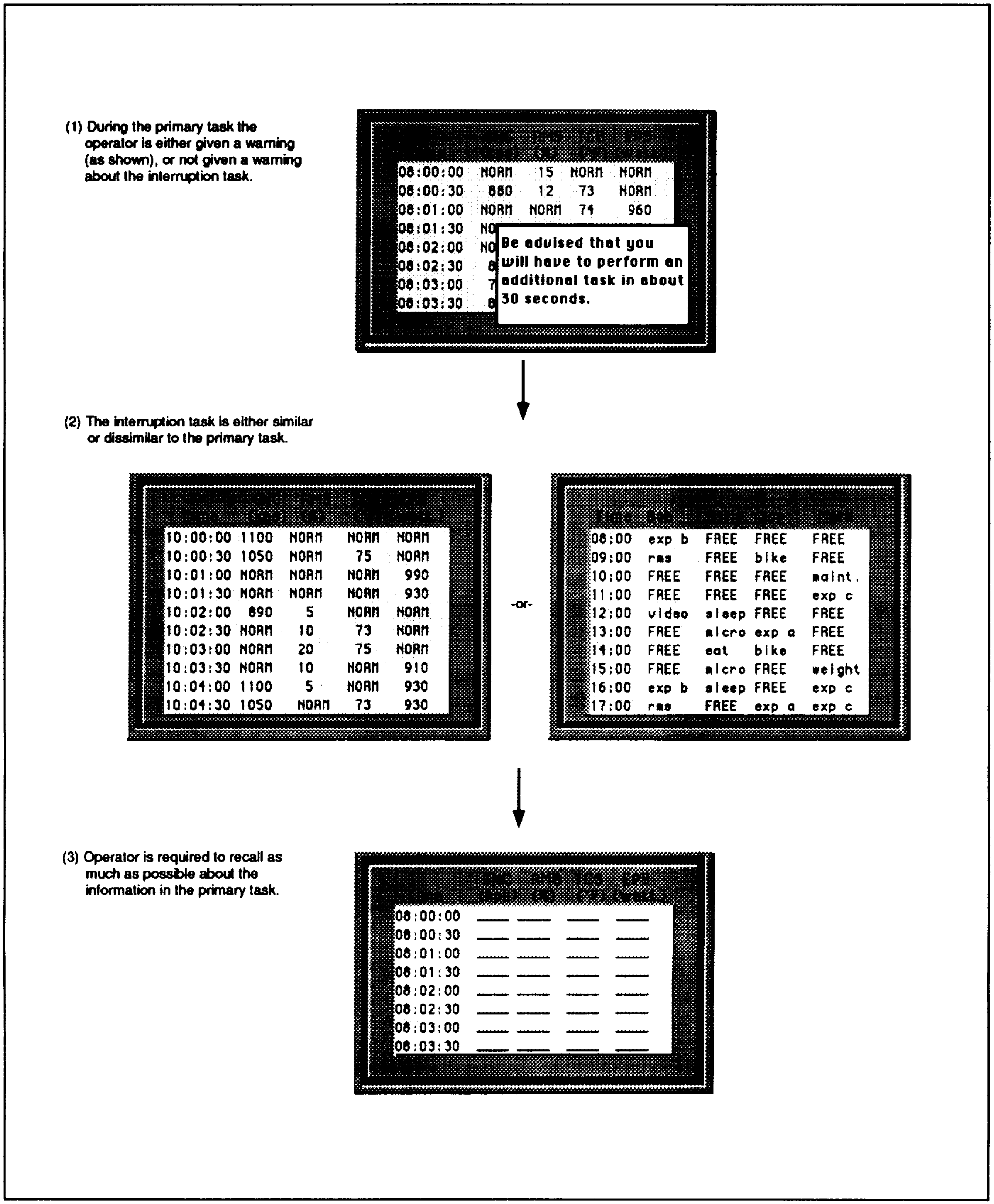


Figure 1. Event flow of one of the multitasking experiments examining the effects of warning and similarity.

Designing a Cursor Control Device for Space Station Freedom

PI: Dean Jensen, Ph.D./SP34
Marianne Rudisill, Ph.D./SP34
Robert P. Wilmington/LESC
Kritina L. Holden, Ph.D./LESC
Mihriban Whitmore, Ph.D./LESC
Reference: HST 27

Since 1989, the Crew Interface Analysis Section (CIAS) in the Man-Systems Division has been performing cursor control device research in the laboratory, KC-135, and Shuttle environments to determine those cursor control device characteristics that would be optimal for use in microgravity. Freedom will be equipped with multiple workstations, which provide command and control capabilities to the crewmember via a direct manipulation interface. In other words, crewmembers will command system components by manipulating on-screen representations of the components. This point-and-click interface is made possible through the use of a cursor control device. Cursor control devices such as a mouse and trackball are commonly used with computers in one-g office and laboratory environments.

Direct manipulation involves three basic operations: (1) pointing, (2) clicking, and (3) dragging. These three operations allow for the full manipulation of objects and text on a display. Given that the time for onboard evaluation is short, a task was needed to meet the following: (1) not involve extensive training or lengthy instructions, (2) provide the minimum basic measures required to adequately evaluate the devices, and (3) be limited in scope to the variables of interest (i.e., device performance). A modified text editing task met all of the above criteria.

The Text Edit Task used in this research involved a common text editing operation—the drag-selection of an area of text. Figure 1 shows a sample Text Edit Task display.

The research plan for this project involved a set of evaluations that progressed from the one-g ground environment to the short-duration microgravity environment of the KC-135 aircraft to the extended microgravity Shuttle environment. A variety of devices have been tested including a mechanical mouse, an optical mouse, an external trackball, a Felix post device, a rackball built into the keyboard, a mouse pen, and a thumb ball. Devices that passed human factors evaluations on the ground and KC-135 were proposed as devices to be tested on the Shuttle.

Three Shuttle evaluations have been completed. The first one, aboard STS-29, consisted of a subjective evaluation of a PC-TRAC external trackball and a Mouse Systems optical mouse. The trackball was preferred, but crewmembers reported that the ball had too much "play" and could be smaller. The second Shuttle evaluation consisted of an experiment aboard STS-41. This experiment compared crew objective performance with a Macintosh portable built-in trackball and an Altra Felix post device using a text editing task requiring pointing, clicking, and dragging. The portable computer was mounted at several different locations on the Shuttle during testing, including a panel on the flight deck, face of a middeck locker, treadmill, and crewmember's lap. The trackball was smaller than that flown on STS-29. Data analysis showed that there was still too much float in the ball mechanism and neither device provided for accurate performance.

Recently, a follow-up cursor control device experiment was performed aboard STS-43. On this flight, the Macintosh built-in trackball, a Mouse Systems optical mouse, a Measurement Systems custom external trackball with restraint rails, and a Measurement Systems custom thumb ball grip device were experimentally compared (fig. 2). The built-in trackball was modified to reduce the "play" in the ball. A workstation environment was created through the use of a shelf that was mounted on the flight deck panels. Crewmembers reported no problems with the modified built-in trackball, and, in fact, overwhelmingly preferred it over the other devices. The thumb ball (fig. 3) had too much "play" in the ball and had a button pressure that was too strong. There was some indication that the external trackball had too much "play" as well, along with a button pressure that was too strong. The optical mouse was reported as adequate, but the lack of a one-piece fixed design made it less preferable than the built-in trackball. Objective data analysis revealed that the built-in trackball provided for the fastest pointing and dragging times and was highly accurate.

The goal of this line of research was to identify cursor control device characteristics that would be optimal in microgravity, without necessarily focusing on a particular design implementation. The following device characteristics have been identified as optimal:

- Fixed, one-piece design
- Serves as a restraint
- No "play" in ball mechanism
- Ball size of approximately 3.8 to 5.1 cm
- Low inertia in ball spin

- Button pressure of approximately 130 to 50 g (as in Macintosh trackball)
- Fast and accurate performance for small as well as large cursor movements
- Button placement below or slightly to the sides of the ball mechanism (where thumb naturally rests)
- Allow for right- and left-handed operation
- Small compact unit, ergonomically designed for a range of user hand sizes

A trackball device is currently baselined for the Space Station Freedom Program, and, if properly designed, will have the majority of the characteristics listed. Specific device recommendations are being provided to the Space Station Freedom Program and to the prime contractor, McDonnell Douglas Space Systems Company. The CIAS looks forward to participating in final testing of the cursor control device provided to the Space Station Freedom Program by McDonnell Douglas.

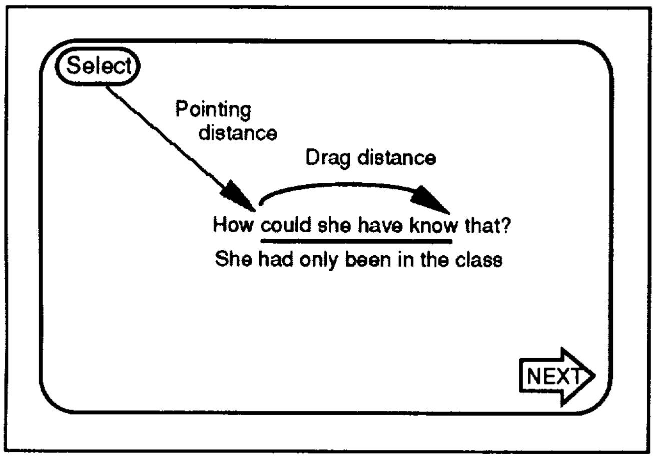


Figure 1. Text Edit Task display screen.

Figure 3. Crewmember using thumb ball cursor controller device.

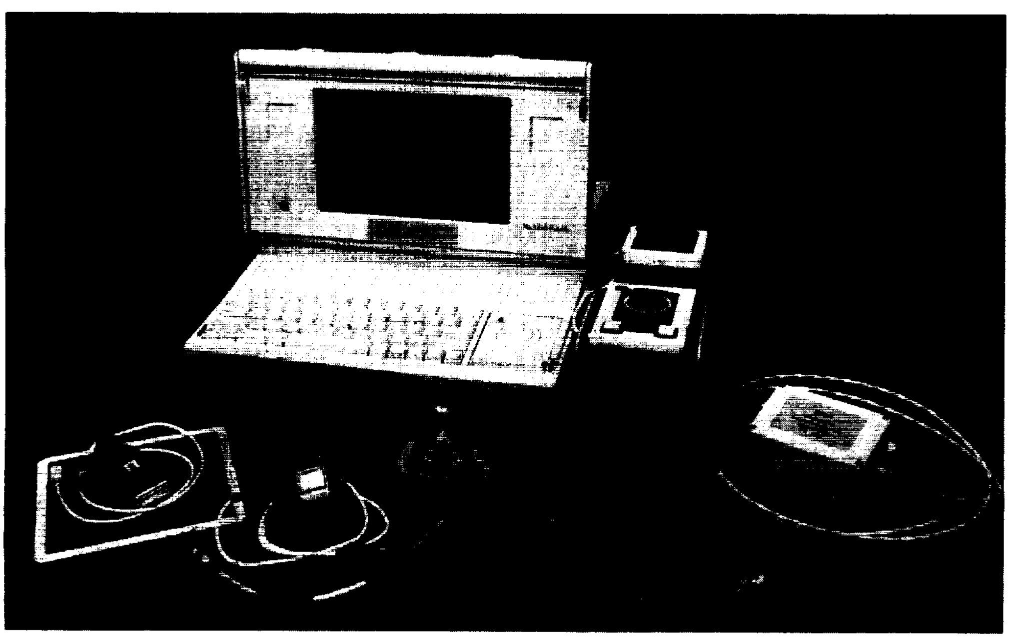


Figure 2. Portable computer shown with a built-in trackball, an optical mouse, an external trackball, and a thumb ball (in a joystick) cursor control device. Also shown are items that were evaluated.

Tools and Methods for User-Intelligent System Interaction Design

PI: Jane T. Malin, Ph.D./ER22
Reference: HST 28

Human operators use intelligent systems to automate and assist in monitoring and in fault management tasks. Effective user interfaces and supporting intelligent system capabilities are critical to the success of these intelligent systems, especially when the monitored systems are complex space systems. The purpose of this project is to prototype methodology and tools to support the design of intelligent systems for aerospace monitoring and fault management by helping designers to maintain awareness of user information needs. These tools support human-computer interaction design so that requirements can be simultaneously developed for three design areas: design of the intelligent system, design of displays, and design of sensor and actuator capabilities of the monitored system.

Last year, a proof-of-concept prototype, the User-Intelligent System Interface Toolkit (UISIT) was completed. The prototype can be used to design interfaces for intelligent systems for fault management that use schematics, diagrams, and models of the structure and function of the managed system. The prototype has several desirable capabilities: (1) separation of the user interface from the intelligent system, (2) object-oriented data-model layer and architecture to handle information transfer between user and intelligent system, (3) early consideration of information exchange requirements between intelligent system and user, and (4) integration of intelligent system interface with conventional software to handle embedded intelligent systems.

In FY91, an evaluation of UISIT prototype tools and methods has been conducted in an application case. UISIT-based methods and tools are being used to support the Space Shuttle Payload Deployment and Retrieval System (PDRS) Decision Support System (DESSY) Project to develop a prototype intelligent fault management support system (fig. 1). The purpose of this effort is to evaluate the underlying human-computer interaction (HCI) development methodology and its support by the tools. The evaluation shows that such user interface tools and methods can effectively promote the consideration of HCI information exchange requirements and design team communication.

User interface tools should support information requirements development and use as well as user interface design and management. Designing the HCI so that the user has the right information at the right time is difficult, and it requires different tools from those that support user interface design. Such tools should support the representation of information exchange items and the interrelationships among these items. Such tools should also represent information requirements in the same module that supports run-time information exchange, thus ensuring that design changes are automatically recorded during implementation.

The design methodology developed with the UISIT prototype tool kit defines information requirements early in system design and supports coordination among design team members. Analysis and preliminary design occur first to derive high-level descriptions of intelligent system functions, tasks, architecture, and HCI. From these descriptions, requirements are derived for the major software component functions and for HCI information exchange. Using information requirements, the design team can be partitioned into smaller groups performing separate, but coordinated, concurrent design of software components. As requirements change in software component implementation, the information requirements can serve as a point of coordination among design team members. Evaluation in the PDRS DESSY case indicated that this focus on information exchange requirements is both feasible and effective. This evaluation will continue in FY92.

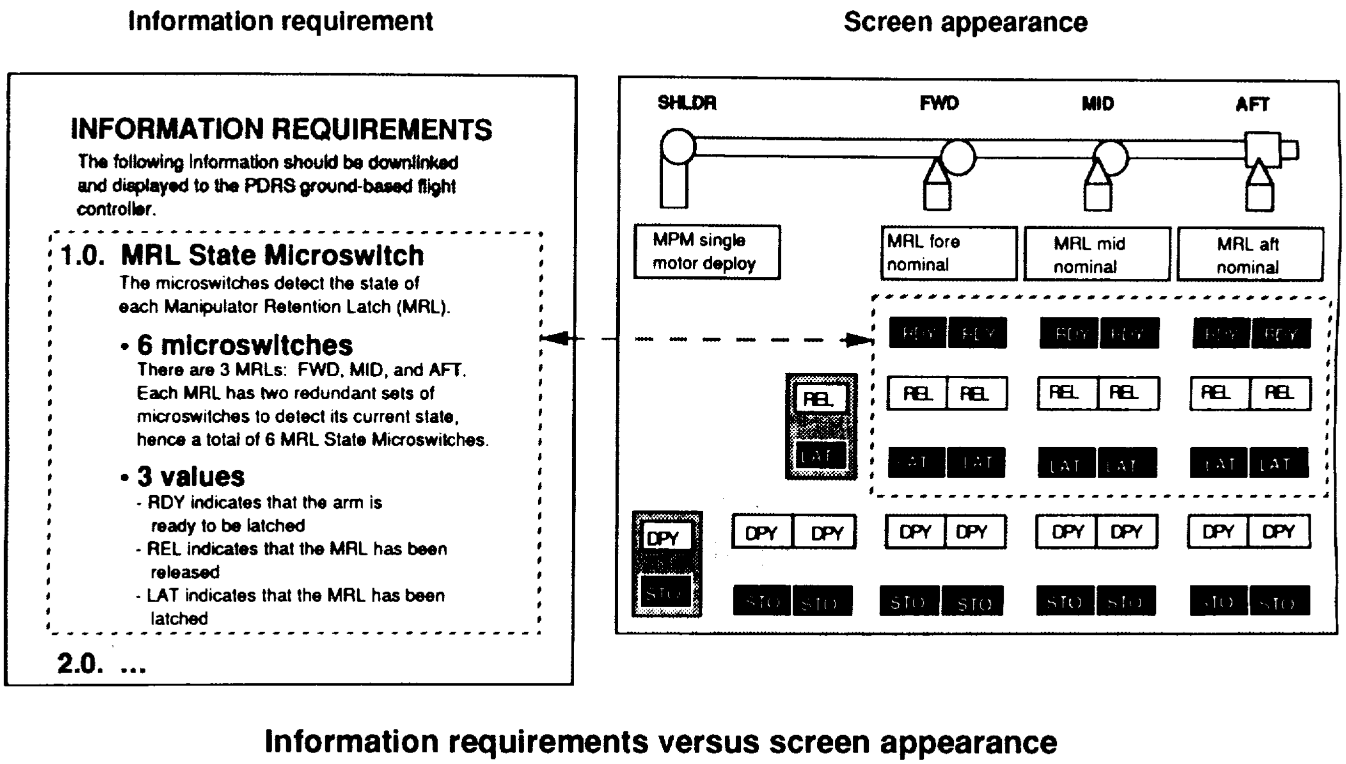


Figure 1. Information requirements for an intelligent system for Space Shuttle PDRS operations.

Human Factors Assessment of Spacelab Missions

PI: **Susan Adam/SP34**
John Gosbee, M.D./LESC
Reference: **HST 29**

Research conducted by the United States, Soviet Union, and other countries has included spaceflight experiments, collection of observational and anecdotal data, and ground-based support research. Spaceflight research has attempted to identify and understand how factors of the space environment can affect human performance in flight. Ground-based research has concentrated on studying analog/simulation environments, model systems, and laboratory experiments to predict human behavior and performance in the space environment and to validate possible countermeasures to ensure adequate performance levels on both an individual and a group level. However, not since the Skylab era have studies specifically addressed human factors, although even at that time only the man-machine interfaces rather than whole man-machine systems were evaluated. Limited studies have addressed such human factors issues as perceptual-motor capabilities, display technology evaluations, and cursor control evaluations, but other operating envelopes of interest to the human factors discipline have largely been ignored.

The Crew Interface Analysis Section at Johnson Space Center is currently conducting Detailed Supplementary Objective (DSO)-904, an evaluation of spaceflight human factors. This DSO is aimed at examining a broad range of human productivity issues deemed critical to mission success from a systems operations perspective. By studying variations between preflight training and in-flight task performance and timeline, factors affecting human productivity during spaceflight may be discerned. This evaluation will specifically analyze the following interfaces to understand how they affect task performance during spaceflight:

- Human-machine interfaces during routine operations such as stowage, restraint, and translation;
- Human-environment interfaces such as noise, vibration, illumination, and perceived air quality; and,
- Human-human interfaces such as communication and documentation of procedures, specifically including the format, level of detail, and means of emphasizing information for Flight Data File, cue cards, uplinked procedures, and verbally uplinked procedures.

The objectives and hypotheses of the five human factors studies were selected for manifest on STS-40 on the basis of feasibility, operational relevance, interviews with previous Space Shuttle and Skylab crewmembers, and review of the literature. Evaluation of stowage and deployment techniques for equipment, crewmember restraint techniques, and management of loose cables comprised one study (fig. 1). The hypothesis of another study was that the noise levels in Spacelab could interfere with performance and potentially cause a temporary threshold shift in hearing. The hypothesis of the third study was that excessive vibration can affect crewmember task performance. A fourth study sought to develop a model to predict the amount of time it takes to complete tasks in zero g as opposed to on Earth (one g). The fifth study investigated several aspects of translation of the crewmembers through the Spacelab/Shuttle connecting tunnel, including: translation aids, differences between crewmembers, and factors affecting equipment transfer.

These evaluations were intentionally designed to be minimally intrusive to the crewmembers and to the mission schedule. The studies were accomplished nonintrusively, examining activities that were already part of existing SLS-1 experiments. The approach was similar to the successful human factors experiments that were performed during the Skylab missions, which are extensively referenced by spacecraft designers, engineers, and operations personnel. The general approach for these studies was an exploratory field study. There were several preflight, in-flight, and postflight activities that were common to all five studies. The preflight process included interviews with crewmembers of previous Spacelab and Skylab missions, observing integrated simulation and training sessions, and interviews with the SLS-1 crewmembers to introduce the questionnaires and sensitize them to aspects of the human factors evaluation. During the mission, crewmembers were asked to complete questionnaires, and audio and video from the mission were monitored. Postflight, video from the mission was analyzed and crewmembers were interviewed and completed another questionnaire. All the STS-40 crewmembers were asked to participate in these general processes. The common method of data analysis was to identify problems or concerns from the questionnaires and mission monitoring, correlate these problems with video and audio sequences, and investigate them further during crew debriefing sessions. The current study not only assessed how crews cope with the on-orbit environment, but identified and studied factors that affect crew productivity and determined several recommendations for the design and timelining of experiments aboard future Spacelab missions as well as aboard Space Station Freedom. Data analysis is completed and the final STS-40 DSO-904 mission report is forthcoming.

DSO-904 has been manifested aboard STS-47/ Spacelab-Japan (SL-J) and STS-50/U.S. Microgravity Lab (USML)-1 both scheduled for launch in 1992. The objectives planned for evaluation aboard SL-J include the continuation of the STS-40 analysis of translation through the Spacelab transfer tunnel, workbench usage (posture and work envelope), and air-to-ground communication with concentration on the international nature of the mission. The objectives planned for evaluation aboard USML-1 include analyses of the in-flight timeline for the use of the Lower Body Negative Pressure apparatus and the vibration isolation system for the ergometer. The acoustic environment will be assessed subjectively by questionnaire and objectively by measurements made with the 1/3 octave band sound level meter. Additionally, on USML-1 the anthropometrics of the glovebox user interface will be analyzed. The data and resulting conclusions of the DSO-904 series of human factors evaluations will be used to establish recommendations, by class of tasks, to aid in the optimal development of systems to accomplish investigations aboard future manned spaceflight missions.

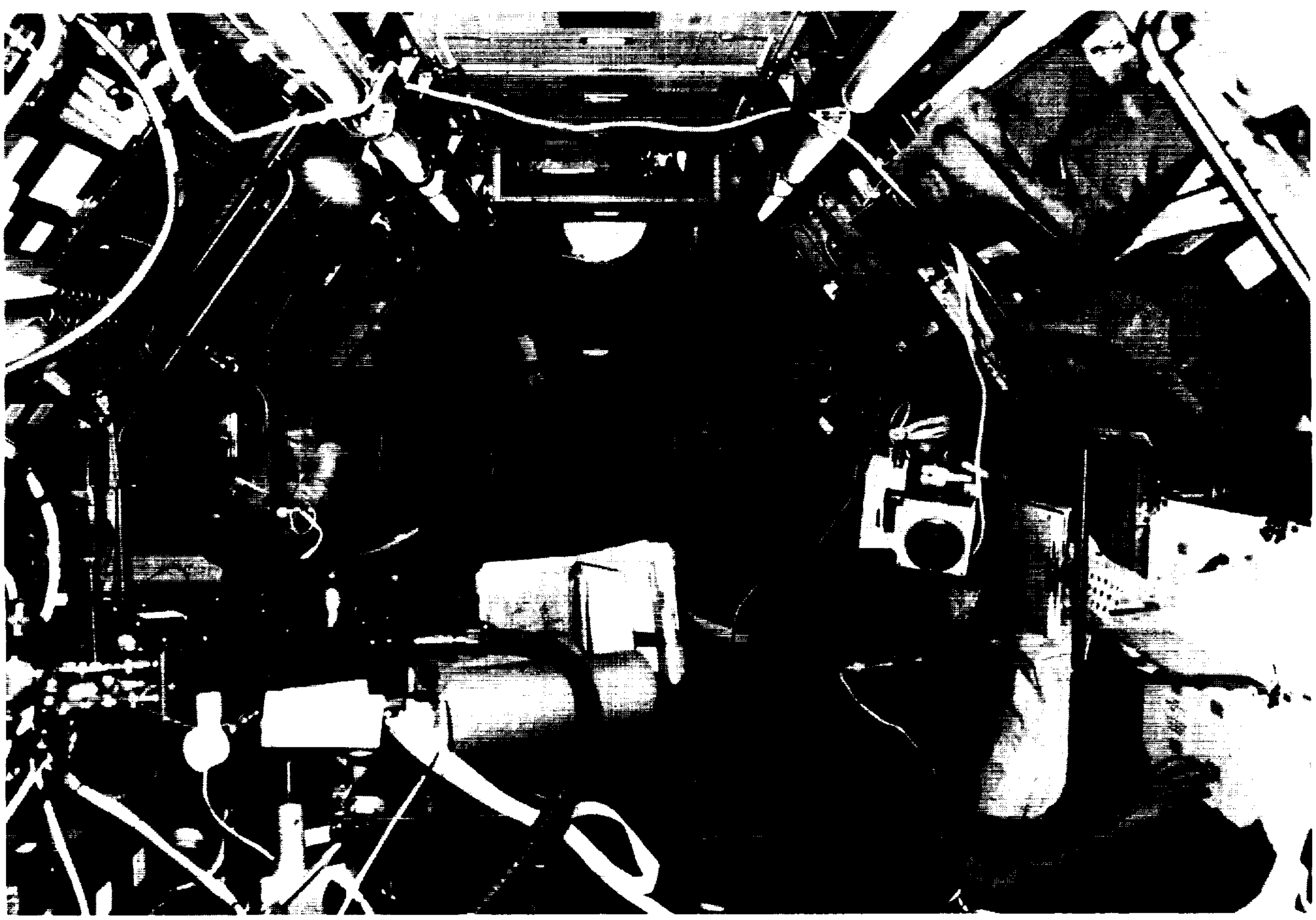


Figure 1. Four STS-40 crewmembers at work in the Spacelab.

Task Network Models of Performance in Microgravity

PI: Susan Adam/SP34
Manuel Diaz/LESC
Reference: HST 30

Spaceflight requires high levels of crew performance in an unfamiliar and stressful environment. Stressors include isolation and confinement, potentially high workloads, and weightlessness. To date, there have been no reports of such conditions leading to seriously degraded performance in U.S. space missions. However, there are many such reports from analogous missions and habitats (submarines, polar bases, commercial aviation, and U.S.S.R. space missions). The Space Station living and working environment may precipitate further problems by introducing additional variables including: higher workloads, longer durations, more heterogeneous crews with more varied and complex tasks, and the possible decrease in the attractiveness of such duties.

Human performance under various workloads and stress conditions in space, critical to the success of spaceflight, has not been systematically studied yet and is not completely understood. However, it is known that performance dynamics can become increasingly significant as mission duration and complexity increase. It is known that human performance is not simply "zero or one," but that it varies as a function of a large number of stressors. Indeed, few Shuttle commanders would propose that the success of a mission is unaffected by the level of performance of the crew. However, to date there is a dearth of research that has attempted to model human performance during the stress of spaceflight. Further, no attempts have been made to quantify performance variability as a function of potential stressors.

This report details the use of human performance modeling software in the task network analysis of a representative manned spaceflight task. The analysis provided the decision support criteria for establishing the utility and usability of the System Analysis of Integrated Networks of Tasks (SAINT) and Generic Systems Analysis Workstation computer modeling techniques, and their potential for further application in analysis of manned spaceflight activities. In addition, the intent was to generate data that would form the foundation for (1) improving current methodologies for assessing workload in the operational space environment, (2) developing models relating workload variables, input variables, crew interaction variables, and individual performance variables, and (3) developing an integrated set of methodologies for the evaluation of performance degradation during extended duration spaceflight.

The remote manipulator system (RMS) payload grapple task was selected for the modeling effort. The grapple task was selected because it is a more complex and critical task than the majority of Shuttle tasks, thus providing a greater performance prediction challenge. Additionally, the grapple task has the potential for completion by single or dual operators. The task was selected prior to STS-37 knowing that actual mission data would soon be available, thus permitting evaluation of the software by comparison of the data yielded by the modeling simulation to that of the "real world." Preflight, several crew RMS training sessions were also observed in the System Engineering Simulator to assist in model development.

Analysis of the RMS payload grapple task and subsequent model development was based on the Integrated Computer-Aided Manufacturing Definition (IDEF) methodology. IDEF provides a structured approach for use in the decomposition of a system into a hierarchy of functions (e.g., control, resources, input and output). A series of models was created using the IDEF concept. First a one-g static model was developed (fig. 1). Then two distinct computer simulation models were developed: a one-g dynamic model and a zero-g model incorporating zero-g performance shaping functions (PSFs). The PSFs were derived from interviews with STS-37 crewmembers and were determined to be essentially equal to zero for this highly trained task. That is, there was no appreciable difference in performance due to microgravity.

Although SAINT is not dedicated to operator workload assessment, it does output operator time requirements and is capable of quantifying attentional demands. A comparison of the time required to perform a task and the time available provides an index of the amount of workload imposed by the task. The payload grapple task required less time in flight than had been allocated for its performance. The one-g model predicted a workload index of 55%; the actual mission workload was measured to be 63%. It was determined that SAINT is an excellent tool, in conjunction with other facilities of the Man-Systems Division, for assessing and enhancing human performance in man-machine systems. Specifically, SAINT could be directed toward improving system efficiency by increasing the understanding of basic capabilities of the human component in the system and the factors that influence these capabilities.

Zero-g PSFs are expected to increase or decrease in-flight task time as a function of the stress attributable to microgravity. Currently, a series of KC-135 studies is planned to further quantify, via a controlled computer-presented task, the additional workload imposed on the operator by microgravity. Additionally, a series of Shuttle flight experiments is manifested to further assess the degree of performance variability attributable to the flight environment by comparing zero-g in-flight performance to one-g training task timelines.

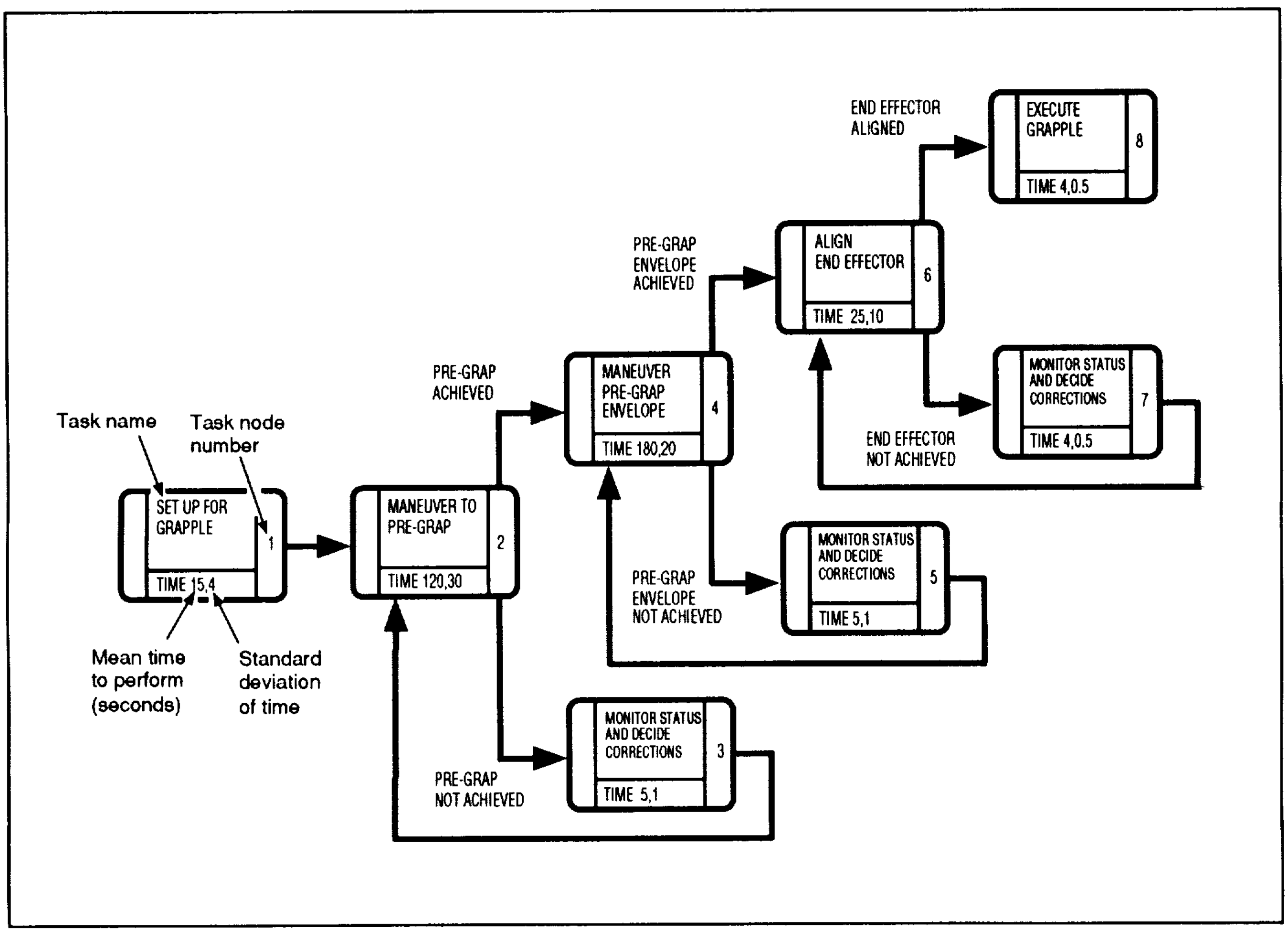


Figure 1. Abbreviated one-g static model of the Payload Grapple Task.

Partial Gravity Simulation Development

PI: **David Ray/SP52**
Vernon Granger/JEC
Gordon Miller/JEC
Brian Petty/JEC
Reference: **HST 31**

To support future manned missions to the surface of the Moon and Mars, a training device is required to duplicate the conditions of reduced gravitational forces or partial gravity as compared to the Earth gravity field. This type of training enables a crewmember to become familiar with the mobility problems associated with suited extravehicular activity exercises. To simulate a partial gravity environment, a means of providing a constant upward force on a trainee while allowing for forward translation is required.

A partial gravity simulator is currently under development by the Man-Systems Division of NASA/ Johnson Space Center. This simulator is a combination of salvaged Apollo-era hardware and recent additions and upgrades made during testing and development. The simulator consists of three major subassemblies:

- Vertical servo mechanism
- Horizontal drive system
- Control console

The most important of these subassemblies is the vertical servo mechanism. The vertical servo mechanism is the method by which a constant upward lift force is provided to the trainee to simulate partial gravity. For simulating a Moon exercise where the gravity field is approximately 1/6 times that of Earth, the vertical servo will provide a constant upward lifting force of 5/6 times the trainee's weight. This is accomplished by a piston/cylinder arrangement, which uses compressed air as the working fluid as shown in figure 1. At the start of a training exercise the trainee, supported to the gimbal fixture, is weighed to obtain the required lifting force. The piston cylinder is then fed with compressed air by adjusting the supply regulator to provide the required upward lift. As the trainee begins walking, the pressure inside the cylinder under the piston head changes. This change in pressure is detected mechanically by the flapper/orifice arrangement. As the trainee takes a step and moves upward, tending to decrease the pressure in the cylinder, the flapper moves up causing less air to be exhausted by the exhaust servovalve and allowing more air to be supplied by the intake servovalve and thus providing the pressure to maintain the constant lifting force. Conversely, as the trainee is descending after taking a step, tending to increase the pressure in the cylinder, the flapper moves down causing more air to be exhausted through the exhaust servo valve so as not to have a buildup of air pressure and maintaining the constant upward lift.

The entire vertical servo mechanism is housed in a box frame, which is suspended from air-bearing shoes that ride on a monorail as shown in figure 1. This is done to minimize the resistance to forward translation. A wire rope cable loop is connected to the vertical servo (fig. 2). The cable is connected by pulleys to a 7.5hp 3ø drive motor. The motor drives the vertical servo either forward or reverse according to the motion of the trainee. Two limit switches are used to detect this motion and are wired to a programmable motor controller that drives the motor.

The control console is an instructor/operator station for setting up the initial lift force by controlling the supply regulator and for monitoring the simulator and trainee's performance during a training exercise. The control console has safety features, which allow for shutting down the simulator vertical servo and horizontal drive system in the event of a system failure.

The Man-Systems Division is currently working towards upgrading the pneumatic and mechanical servos and valves with state-of-the-art proportional valves and sensors. These developments are currently being conducted on a temporary test-bed (fig. 3) in building 9B where plans for installation of a permanent Partial Gravity Simulator are in work.

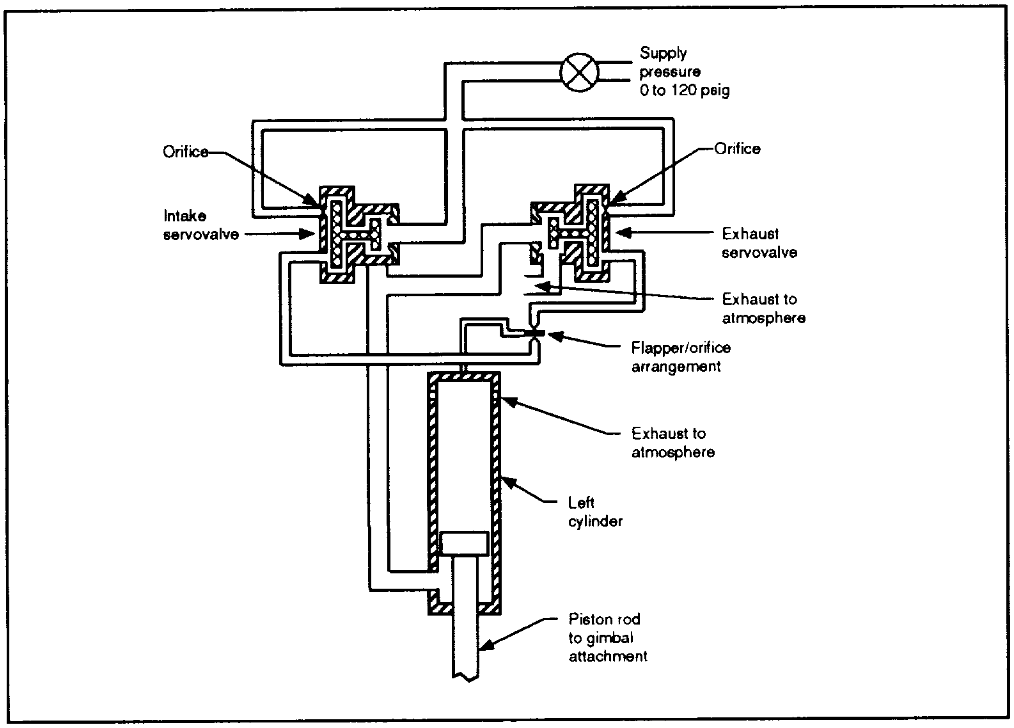


Figure 1. Partial Gravity Simulator pneumatic piston/cylinder schematic.

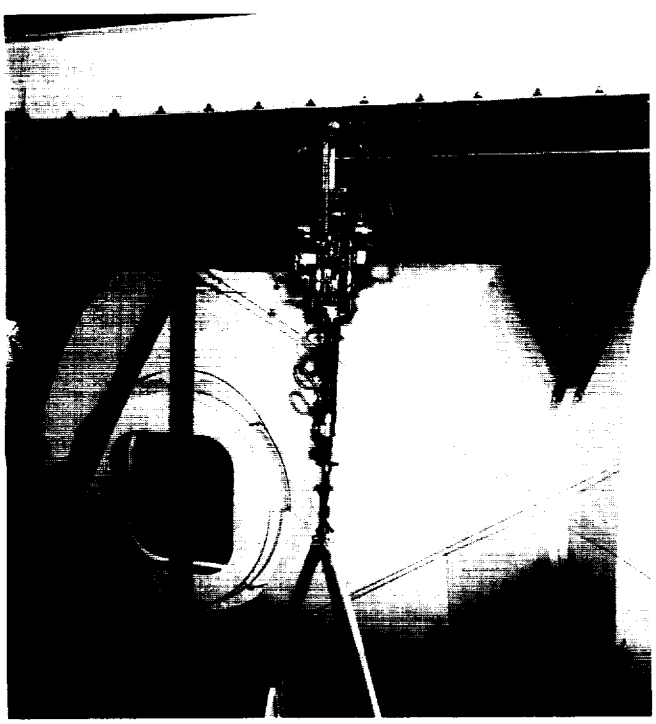


Figure 2. The vertical servo assembly for the Partial Gravity Simulator.

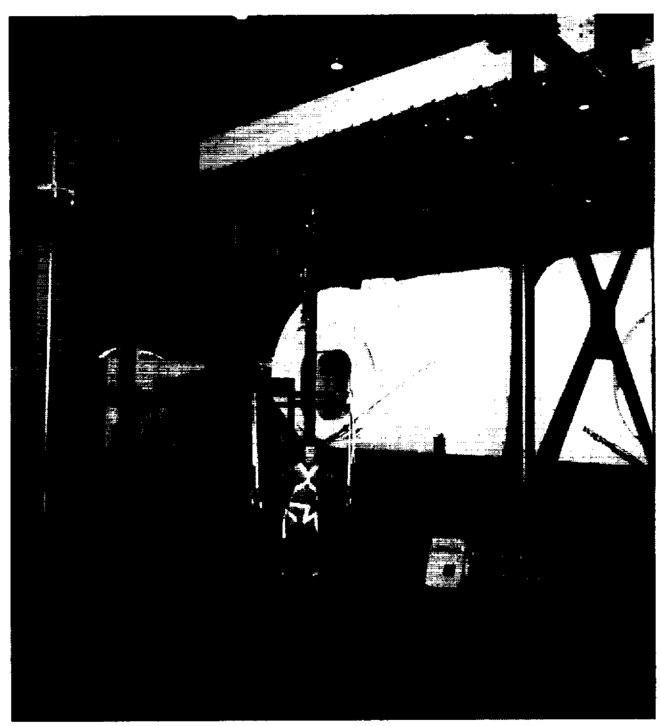


Figure 3. Partial Gravity Simulator test-bed with gimbal and control console.

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C Language Integrated Production System

PI:	**Gary Riley/PT4**
	Chris Culbert/PT4
	Brian Donnell/PT4
	Robert T. Savely/PT4
Reference:	**HST 32**

Conventional programming languages, such as FORTRAN and C, are designed and optimized for the procedural manipulation of data (such as numbers and arrays). Humans, however, often solve complex problems using very abstract, symbolic approaches that are not well suited for implementation in conventional languages. Although abstract information can be modeled in these languages, considerable programming effort is required to transform the information to a format usable with procedural programming paradigms.

One of the results of research in the area of artificial intelligence has been the development of techniques that allow the modeling of information at higher levels of abstraction. These techniques are embodied in languages or tools, which allow programs to be built that closely resemble human logic in their implementation and are, therefore, easier to develop and maintain. These programs, which emulate human expertise in well-defined problem domains, are called expert systems. The potential payoff from expert systems is high: valuable expertise can be captured and preserved; repetitive and/or mundane tasks requiring human expertise can be automated; and uniformity can be applied in decision-making processes. The availability of expert system tools has greatly reduced the effort and cost involved in developing an expert system, and an entire industry has grown to support the development of these types of specialized tools.

Despite the wide variety of expert system tools available, expert systems had generally failed to make a major impact in application environments by the mid-1980s. In part, this failure resulted from a lack of options for deploying expert system applications within conventional computing environments. To solve this problem, the Software Technology Branch at the Johnson Space Center developed the initial version of the C Language Integrated Production System (CLIPS) in 1985. CLIPS was designed to address several issues key to NASA. Among these were the ability to run on a wide variety of conventional hardware platforms, the ability to be integrated with and embedded within conventional software systems, and the ability to provide low cost options for the development and delivery of expert systems. At the time of its development, CLIPS was one of the few tools that was written in C and capable of running on a wide variety of conventional platforms. CLIPS is a continually evolving product with new features and capabilities added on a regular basis. The latest version of CLIPS, version 5.1, was released in October 1991. Machine-specified interfaces have been developed for Apple Macintosh, IBM PC MS-DOS compatible, and X-Window systems. Figure 1 shows the CLIPS interface for the Macintosh computer. A version of CLIPS written completely in Ada, CLIPS/Ada, has also been developed.

Although CLIPS was originally developed by NASA for creating aerospace-related expert systems, it has been put to widespread use in a number of fields. CLIPS has been made available to the general public for a nominal fee through the Computer Software Management and Information Center, the distribution point for NASA software. The current release of CLIPS is being used by more than 3300 users throughout the public and private sector. At the First and Second CLIPS Conferences held in August 1990 and September 1991, respectively, more than 120 papers were presented by representatives of the Government, industry, and academia on a diverse range of topics. Because the CLIPS source code is readily available, numerous groups have saved man-years of development time by using CLIPS as the basis for their own expert system tools. In general, the development of CLIPS has helped to improve the ability to deliver expert system technology throughout the public and private sectors for a wide range of applications and diverse computing environments.

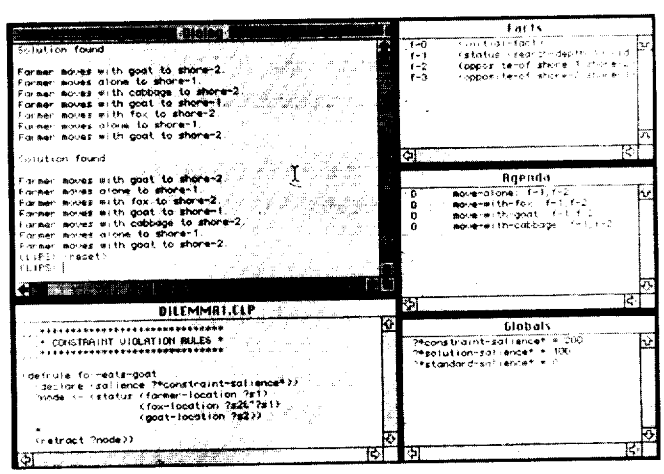


Figure 1. CLIPS Macintosh interface.

Advanced Software Development Workstation

PI: **Ernest M. Fridge III/PT4**
Charles L. Pitman/PT4
Reference: **HST 33**

NASA has many complex software systems that contain millions of lines of code. The development, use, and maintenance costs of such complex information systems are very high. The challenging goal of computer-aided software engineering (CASE) is to reduce the cost of large, complex software systems while improving their quality. The objective of the CASE research and development being performed under the Advanced Software Development Workstation (ASDW) project is to provide productivity enhancements that will help to achieve this challenging goal and thus benefit a broad range of NASA programs, such as the Software Support Environment, the Space Station Control Center, and the Flight Analysis and Design System (FADS), which is used to support the Space Shuttle and the Space Station Freedom.

The ASDW is applying knowledge-based technology (sometimes called expert system technology) to all phases of the software development, use, and maintenance life cycle (except system testing). The ASDW task is composed of four subtasks:

- Parts Composition System (PCS) with Engineering Script Language (ESL),
- INTelligent User Interface development Tool (INTUIT),
- Framework Programmable Platform (FPP) with Configurable Control Panel (CCP) and IDEF3, a graphical process description capture method, and
- The development of knowledge engineering methods and applications to test and prove these technologies.

The PCS/ESL is a composition system that allows aerospace engineers with minimal programming experience to develop software applications easily by connecting reusable components. INTUIT is a knowledge-based shell that, once configured for a complex application such as a trajectory simulation, allows users to set up the input data streams easily for runs so that programs function properly the first time. The focus of the FPP subtask is the management and control of the software development process within an integrated life cycle environment. Specifically, the focus of the FPP is the development of a horizontal tool, CCP, for describing, managing, and controlling the system development processes used on large complex projects. At the heart of the CCP will be a tool that implements the graphical IDEF3 method for describing complex processes. The knowledge engineering methods being developed under the fourth subtask provide the steps that should be followed to engineer INTUIT-, ESL-, and CCP-type knowledge bases. The applications being developed to test these software technologies are carefully chosen so the benefits of these technologies will be directly demonstrated to potential users. For example, the data organization scheme and the screen presentation methods from an INTUIT application developed for the simulation program called Space Vehicle Dynamics Simulation (SVDS) were delivered to the Rockwell Orbit Design Group for use in the FADS.

Currently, the ASDW supports the reuse of software and data. The reuse of data, supported by knowledge-based assistance, provides an opportunity for significant productivity enhancement in the use of complex computer programs. For example, extensive user time is often required for preparing and debugging input data to very large trajectory simulation programs. As mentioned above, an intelligent user interface (IUI) was developed by configuring the INTUIT shell for the SVDS program (fig. 1). The IUI is inserted as a new layer between the user and the input "data deck." Previously, the user had to set up a data deck (which may contain hundreds of data sets) with a line editor and submit it to the "Generalized Input Processor" (QQINPT), and then to SVDS itself, which ran the trajectory simulation and generated the output. With the new IUI layer, the user interacts with a user-friendly graphical interface instead of a line editor, and the data deck is automatically translated into QQINPT format. Thus, the user sees the input data in a well-organized, natural language style. Access to on-line context-sensitive help is available by pointing and clicking. The INTUIT knowledge base contains information about the SVDS variables and constraints, which means that potential errors can be prevented (or detected and reported) before the data deck is submitted to be run. This will reduce the number of unproductive runs made. All the users who participated in the tests of this IUI were very satisfied with it. Building an input data deck with the IUI proved to require from one-half to one-fifth the time needed using the typical SVDS interface.

C-2

The IUI for SVDS has demonstrated the usefulness of applying knowledge-based technology to making complex software easier to use. The total ASDW project is continuing its efforts to bring the best CASE technology to NASA to make the complex information systems required for space exploration easier to develop, use, and maintain.

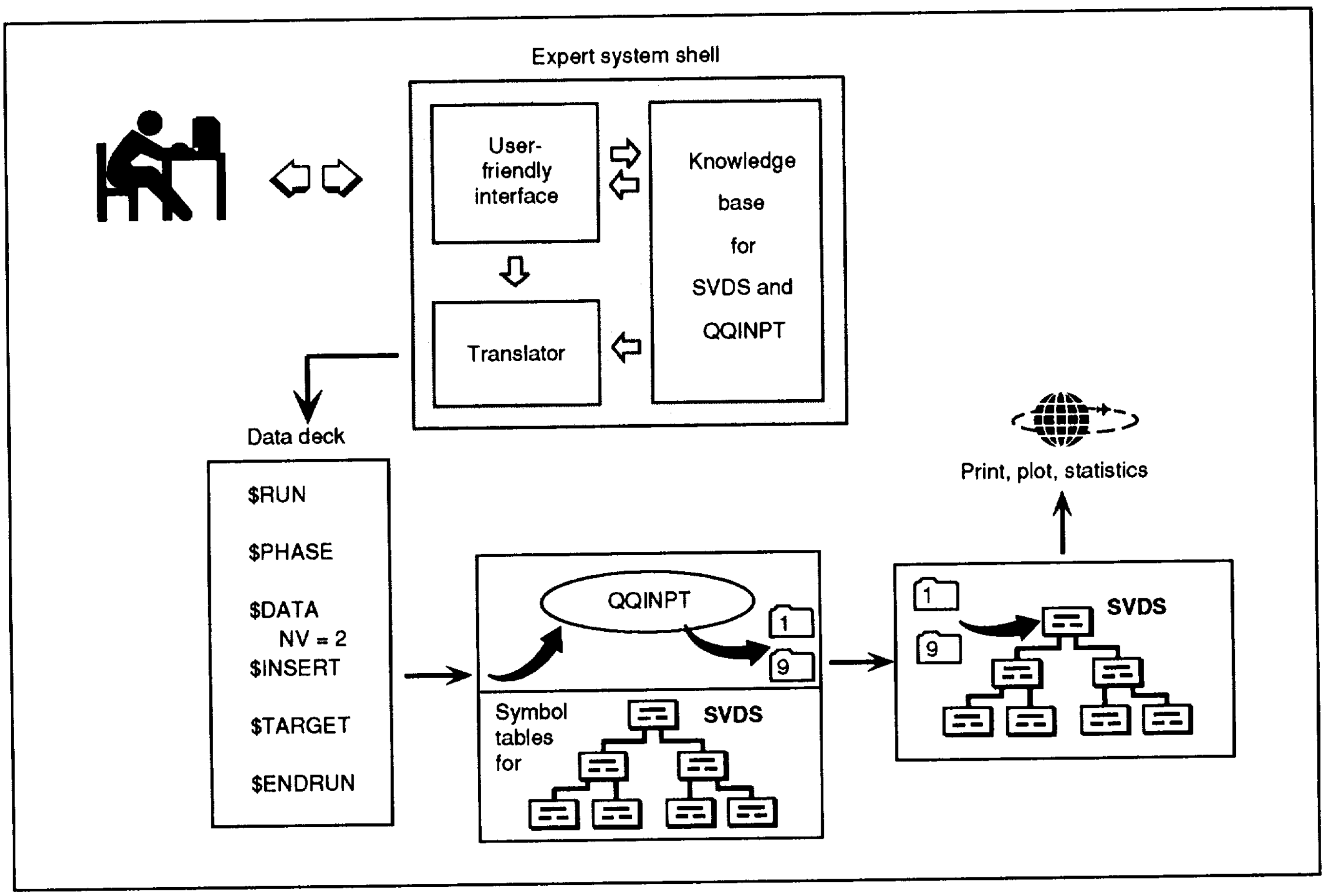


Figure 1. Intelligent user interface for SVDS.

Intelligent Tutoring Systems Integrated with Simulators

PI: Thomas T. Chen/Global Information Systems
Diann E. Barbee/Global Information Systems
Robert T. Savely/PT4
Reference: HST 34

Global Information Systems has developed an intelligent computer-aided training (ICAT) system to be used with NASA simulators of the Shuttle robotic arm. A kinematic model of the arm is used on all but one of the Space Shuttle simulators as well as on a stand-alone version called the "P2T2," which is hosted on a Silicon Graphics workstation. Prior to Global's work, no built-in capabilities for training, performance monitoring, or evaluation feedback existed for any of these simulators; all training and evaluation had to be performed by human instructors.

The need for integrated, expert system-based training functions such as performance monitoring and evaluation in training using simulators is evident. These simulations usually deliver very complex mission training scenarios and are quite expensive to operate. For example, the Shuttle Mission Simulator at Johnson Space Center can simulate 56 subsystems with 6800 possible malfunctions. In addition, four teams of up to eight highly qualified instructors are required to support training on this one simulator. The number of factors effective in the simulation at any one moment can accrue exponentially as the number of crewmembers, instructors, other support personnel, active systems, relevant switches, and malfunctions increase and interact.

Clearly, a pressing need exists for monitoring and evaluation capabilities integrated with current and future simulators. Such capabilities would allow training on simulators to become more efficient, uniform, objective, and less expensive. Also, the missions supported by these simulators would greatly benefit from having built-in tutors to maintain highly perishable operator skills (most specifically, cognitive-based skills) in the field, for example, on the Space Station.

In the implementation of this ICAT system funded by this Small Business Innovative Research Program, two goals have been deemed of paramount importance: (1) enhancing the adaptability of the system to other domains, and (2) easing maintenance of P2T2 and the system. In line with these goals, the following general approach has been taken:

- Minimize the modification of P2T2. As the P2T2 simulator is modified and enhanced, it is desirable to see those changes propagated to the P2T2/ICAT. The number of changes to P2T2 required by the ICAT has been minimized to make it easier to maintain the P2T2 portion of the trainer.
- Segregate P2T2 and the ICAT system as much as possible. To make the ICAT portion of P2T2/ICAT adaptable to other domains and new tasks, the ICAT portion and the P2T2 portion of P2T2/ICAT will communicate through well-defined interfaces.
- Minimize assumptions about the remote manipulator system (RMS) domain. The ICAT system should make as few assumptions about the RMS domain as possible. This will make the system more portable to other task-oriented domains.

A system diagram is shown in figure 1. The ICAT system has two modes besides the (unmonitored) simulation mode:

- Tutorial Mode: The Tutorial Mode consists of an ordered series of part tasks (using the simulator) that allows guided practice with the knowledge and various skills associated with flying the arm. Students must master each part task at increasing levels of difficulty before proceeding to the next task.
- Skill Maintenance Mode: The Skill Maintenance Mode is used once the student has mastered all the part tasks in the Tutorial Mode. The ICAT system first monitors unobtrusively as the student performs one of the two whole tasks associated with flying the arm (e.g., deploy or retrieve a payload). Regardless of student performance, no tutoring or evaluative feedback is given to the student during this testing.

Future work will focus on the integration of the P2T2/ICAT for the robotic arm with a different simulator, for example, the Manipulator Development Facility (a one-g arm). Such technology could also be used to automate scenario generation based on performance data. In addition, this technology could be transitioned into an onboard training/advisory system.

Summary of important conclusions: (1) Future simulators should have a built-in student diagnostic and evaluation component, as well as remedial training capability, and (2) the ICAT system methodology is feasible for producing these types of training capabilities.

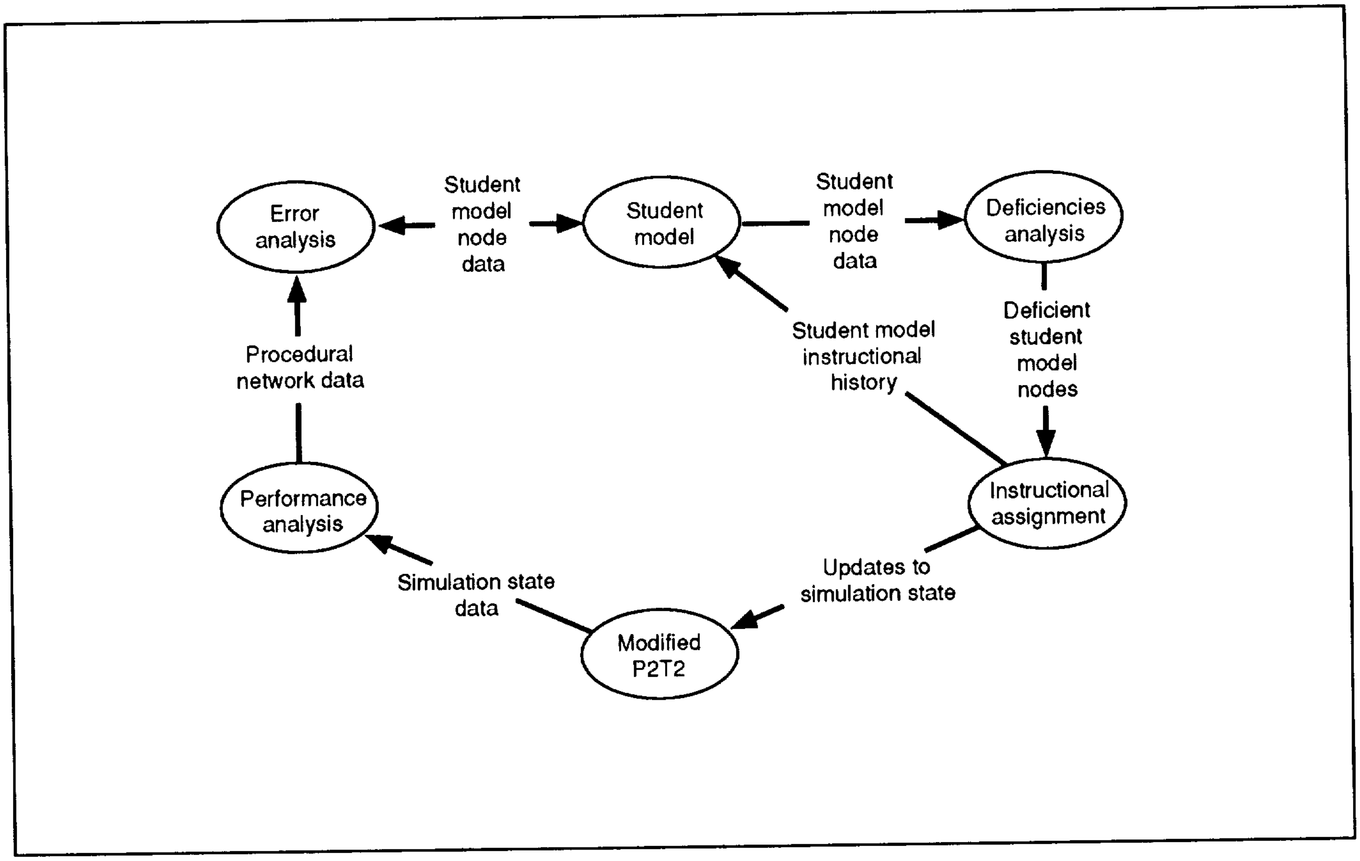


Figure 1. System diagram of the RMS ICAT system.

The Intelligent Physics Tutor

PI: **Robert T. Savely/PT4**
Dr. R. Bowen Loftin/University of Houston-Downtown
Reference: **HST 35**

The integration of the computer into the precollege instructional program began in the 1960s and has accelerated with the availability of inexpensive computing hardware and a growing amount of useful instructional software. Unfortunately, the bulk of the computer-aided instruction today is limited to rather simple programs that are useful for drill-and-practice, automated "page-turning," and the administration of objective examinations. The Intelligent Physics Tutor exemplifies a new generation of instructional software that relies upon artificial intelligence technology to provide individualized assistance to students in a number of educational settings. Intelligent Tutoring Systems will complement other new technologies to provide an integrated learning environment that has the potential to revolutionize instructional delivery and permit every student to acquire knowledge and skills under optimal conditions.

Since 1986, the Software Technology Branch at NASA/Lyndon B. Johnson Space Center and the University of Houston-Downtown, with support from the Office of Space Flight, have been actively developing intelligent computer-aided training (ICAT) systems for use within NASA by astronauts, flight controllers, and systems engineers. The NASA Technology Utilization Program is supporting the application of this ICAT technology to the development of an intelligent tutoring system for introductory physics. The tutor is designed to provide an interactive environment for the application of physics concepts to the solution of problems. The principal goal of the tutor is to enable the student to efficiently acquire problem-solving skills necessary for successful mastery of high school or introductory college physics. The tutor is intended for integration with the lecture and laboratory portions of the typical instructional program. Its strength lies in its ability to continually observe the student develop problem solutions and to intervene (fig. 1), when appropriate, with assistance specifically directed at the student's difficulty and tailored to the student's skill level and learning style. Student progress through the tutor is governed by a global strategy that evolves the complexity of problems presented to the student at a rate suitable for that individual. In addition, the curriculum organization and problem repertoire can be altered by the teacher to match that of the teacher's own textbook and instructional strategy. This same facility enables the teacher to examine the performance models of individual students or of entire classes. The tutor has been designed to facilitate its application to other problem-solving domains, such as chemistry, mathematics, and engineering.

During FY91, the project was brought to a conclusion with the completion of problem sets for the areas of 1- and 2-dimensional kinematics and dynamics. In addition, an application known as the Teacher's Window was completed. This latter application permits teachers to view student performance (fig. 2) collectively or individually, modify the curricular content of the tutor, and adjust the problems presented to a given student or class. The tutor is currently in use in high school physics classes at Clear Creek High School in League City, Texas, and at West High School in Columbus, Ohio. Evaluations of the tutor in these institutions have been exceptionally positive and a controlled study, conducted by Memphis State University, is now under way. The FY92 goal is the licensing of the tutor for commercial distribution and its use as a foundation for building additional tutors.

Figure 1. A typical screen during use of the Intelligent Physics Tutor.

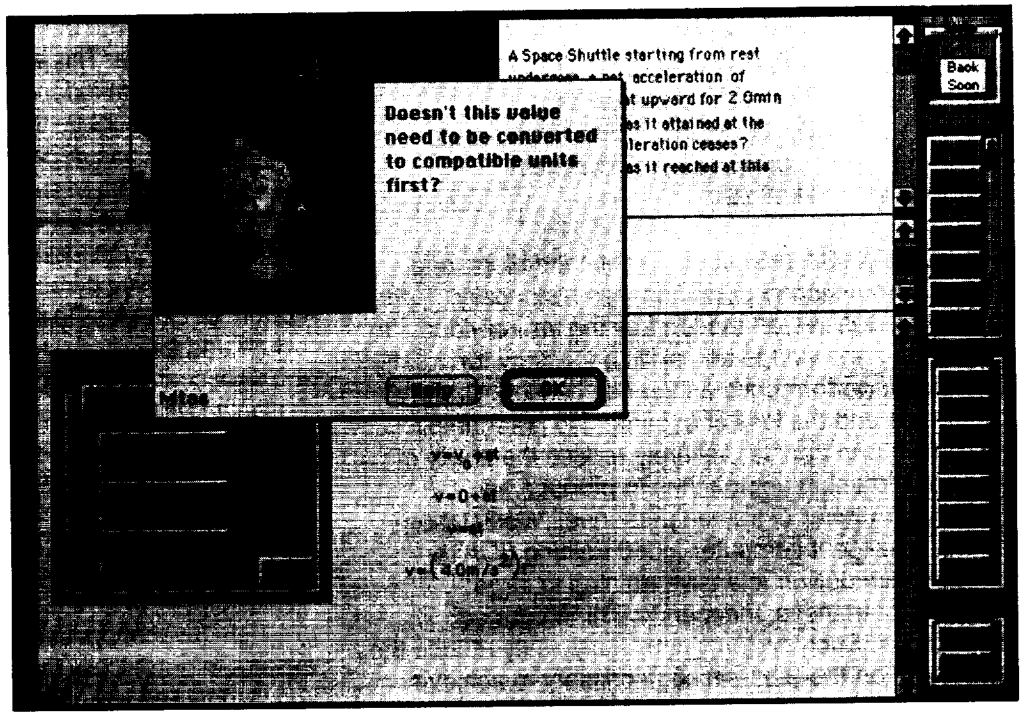
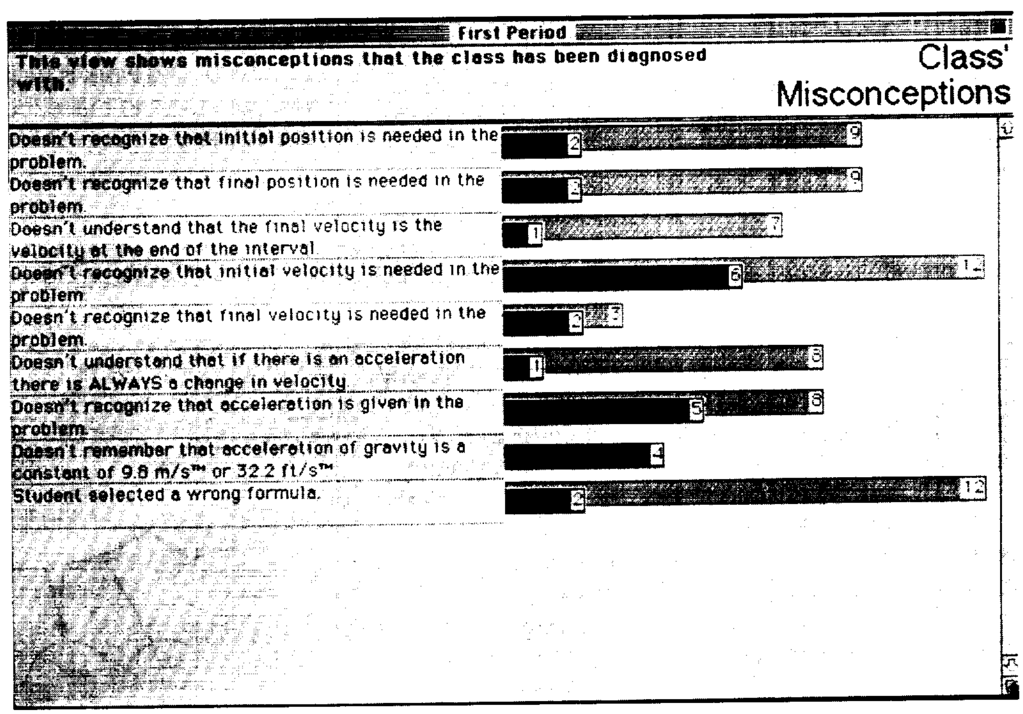


Figure 2. The Teacher's Window, in use to examine the performance of an entire class of students.



Intelligent Computer-Aided Training

PI: Robert T. Savely/PT4
Dr. R. Bowen Loftin/University of Houston-Downtown

Reference: HST 36

Training of NASA astronauts, flight controllers, and other ground support personnel has historically required extensive on-the-job training for individuals to acquire the knowledge and skills necessary for acceptable performance and/or certification. Current flight rates and the loss of experienced personnel to retirement and transfer severely reduce the ability of traditional training approaches to produce an adequate number of trained personnel. Workstation-based, intelligent computer-aided training (ICAT) systems can deliver intensive training to large numbers of trainees, independent of integrated simulations. Such systems can significantly reduce the amount of on-the-job training necessary to achieve acceptable levels of performance.

As figure 1 illustrates, ICAT systems bring artificial intelligence, training technology, simulation, and other software technologies to bear on the problem of training. The role of artificial intelligence in ICAT systems is to model the behavior of both experts and novices in the performance of a complex task. In addition, the expertise of a trainer is modeled and used to determine the feedback given in response to trainee errors and to design increasingly challenging simulations to meet training goals. Thus, the efforts of both an expert in the task and an expert trainer are simultaneously applied to each trainee. Such systems offer increased efficiency and reduced cost in training and provide uniform and verifiable training, enhancing safety and the probability of mission success.

During FY91, the main propulsion pneumatics (MPP) ICAT system, under development for Kennedy Space Center (KSC), was completed and delivered (fig. 2). The instrument pointing system (IPS) ICAT system, supported by Marshall Space Flight Center (MSFC), was nearly completed (fig. 3). Its projected delivery date is October 31, 1991. The MPP/ICAT supports the training of test engineers in the procedures used to prepare the Space Shuttle MPP system for flight. The system incorporates schematics that give engineers access to the system simulation and provide the foundation for training in fault detection, isolation, and reconfiguration.

Work has also been completed on the general ICAT architecture. This architecture is designed to segregate domain-independent portions of the ICAT system and to facilitate the adaptation of the architecture to new applications. A patent application for this general architecture has been submitted by the Johnson Space Center (JSC). Goddard Space Flight Center (GSFC) as used the ICAT architecture to develop a prototype system for training personnel in satellite operations. McDonnell Douglas Corporation has taken the architecture and used it to develop a system for training crew and flight controllers in the operation of the Space Station active thermal control system.

Progress in the creation of a general-purpose development environment for ICAT systems—a suite of software tools to aid trainers in using the general ICAT architecture to build specific applications—has also been made. During FY91, the Task Analysis/Rule Generation Tool (TARGeT) was designed and brought to a beta level of development (fig. 4). This tool assists experts in graphically describing procedural knowledge and will ultimately serve to build and maintain the knowledge bases used by ICAT applications. Work was begun to implement the knowledge-acquisition tool in Windows 3.0 and C. Elements of an ICAT interface development environment in X-Windows were also completed during 1991. In summary, a robust and extensible "core" architecture for ICAT systems has been achieved, and work is well along in the creation of software tools to make the use of this architecture in the building of new applications efficient and effective.

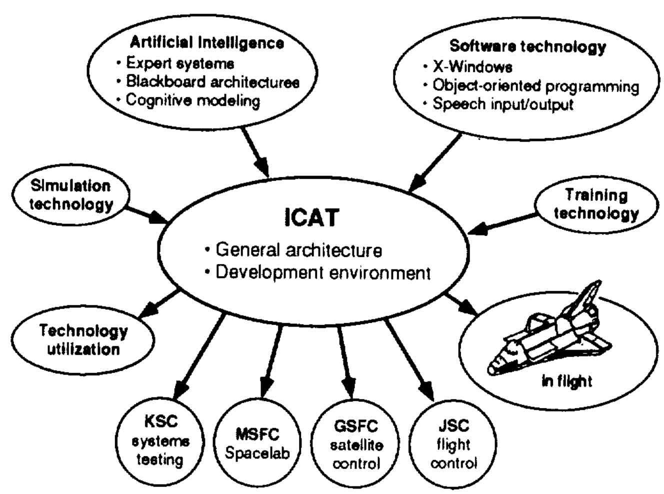


Figure 1. ICAT systems.

Figure 2. MMP/ICAT system.

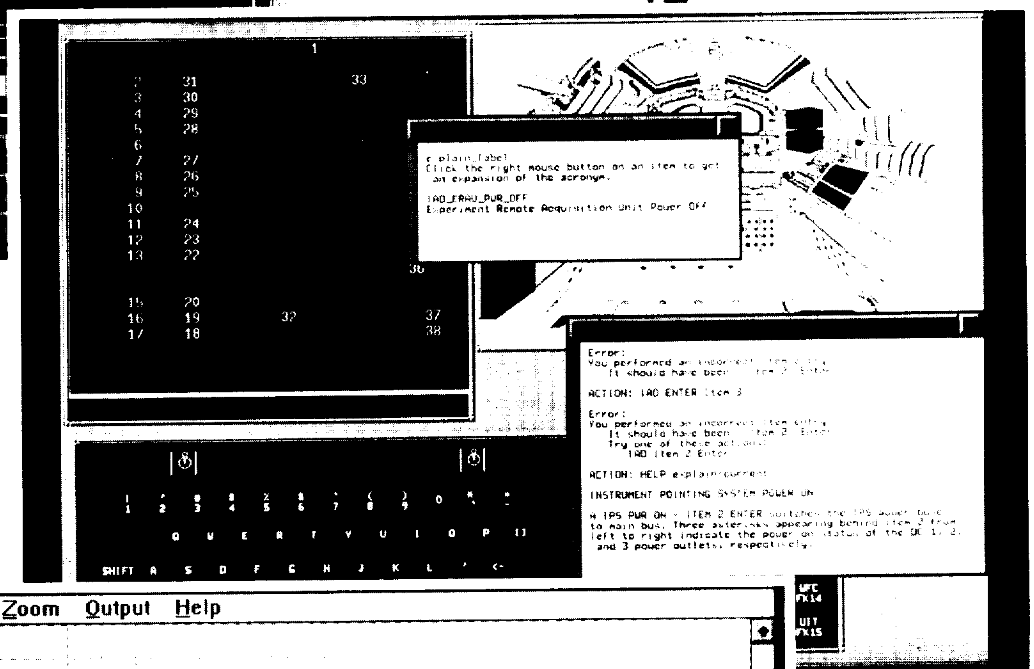


Figure 3. IPS/ICAT system.

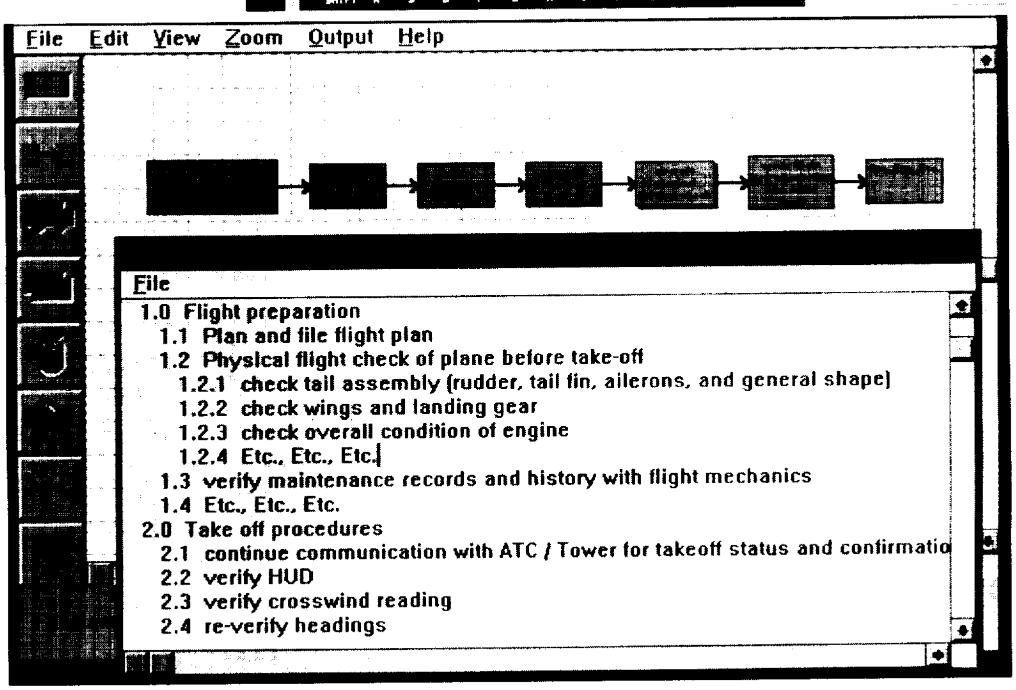


Figure 4. TARGeT.

Passive Knowledge Acquisition System

PI: **Vince Kovarik/**
Software Productivity Solutions, Inc.
Robert T. Savely/PT4
Reference: **HST 37**

The acquisition and application of expert knowledge to complex reasoning tasks remains a human-intensive activity. Efforts to directly extract knowledge from domain experts have not lived up to expectations. Current tools for knowledge acquisition fall far short of the capabilities required to support direct acquisition from the expert. This is because the tools previously developed focused on providing the knowledge engineer with powerful abstractions for building the representation of the acquired knowledge, not on the actual acquisition process. Consequently, current endeavors must rely heavily on the knowledge engineer to both extract and appropriately represent the knowledge of an expert.

The goal of this project is to develop an approach to the direct acquisition of knowledge from experts by emulating a human knowledge engineer. Consequently, this effort is not intended to produce a software environment for use by the knowledge engineer. Rather, the passive knowledge acquisition system (PaKAS) is designed as an interactive system that "observes" the expert in the performance of a task. Following this observation, PaKAS elicits the expert's rationale and background knowledge that led to the observed actions and develops a rule-based representation of the acquired knowledge.

The observation of an expert by an automated system rests on certain assumptions and concessions regarding the actual mode of observation. Of course, PaKAS does not visually observe a human carrying out a task. PaKAS instead provides a simulation of the task to be observed and monitors the interactions of the expert with the simulation—identifying the actions taken by the expert in response to simulation stimuli, noting the objects acted upon by the expert, and recording the changes of state brought about by the expert's actions. The expert need have no knowledge of the observations that are under way as the task is performed.

The PaKAS project builds on previous work at the Johnson Space Center. In particular, the vacuum vent line intelligent computer-aided training system, developed by the Software Technology Branch (PT4), provides the simulation upon which the original implementation of PaKAS is built.

Figure 1 shows the basic architecture of PaKAS. The results of the Phase I effort have demonstrated the feasibility of implementing a more powerful and robust version of PaKAS that could ultimately be integrated with the large-scale simulators that are available at the NASA field centers. Such systems could provide access to the expert knowledge of NASA astronauts and ground support personnel in a manner that avoids the intrusions and lack of domain context that characterize the usual knowledge acquisition process.

During FY91, the project moved from a Phase I to a Phase II Small Business Innovative Research Program. The Phase II effort will be focused on moving the PaKAS architecture from Lisp to C in a Unix environment. In addition, the system will be used to analyze data from the Shuttle Mission Simulator as a means of automating the process of learning how complex human tasks are performed (e.g., Shuttle approach and landing).

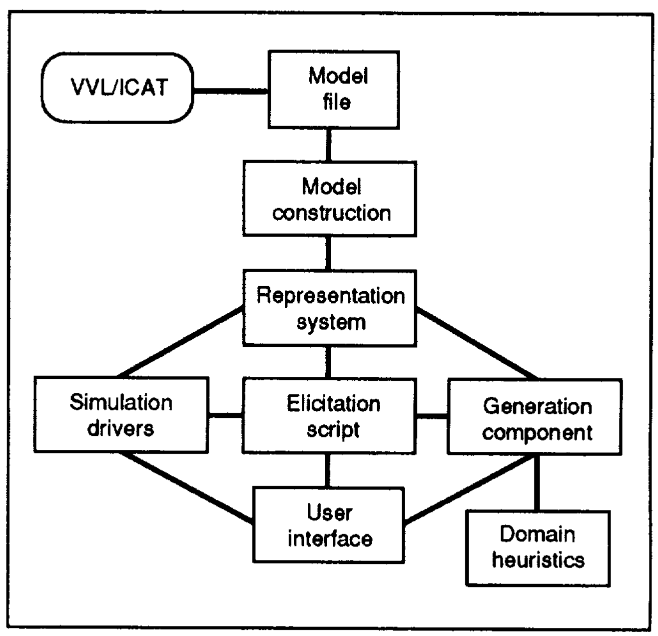


Figure 1. PaKAS architecture.

SimTool: An Integrated Environment for Simulation Construction, Operation, and Maintenance

PI: Ernest M. Fridge III/PT4
Randall D. Barnette/LinCom Corporation

Reference: HST 38

SimTool is a 2-year research and development project under the NASA Small Business Innovative Research (SBIR) Program. The objective of the SimTool effort is to develop a software environment for the integration, operation, and maintenance of simulation software. As specified in the NASA SBIR Program, this Phase II SBIR effort will result in a marketable product. SimTool will be developed during the 2-year period of July 1990 through June 1992. During this period, development will progress through requirements analysis, design, implementation, integration, verification, and validation phases. System-level requirements were defined based upon results from the Phase I SimTool SBIR effort (completed July 1989) and discussions with LinCom and NASA engineers.

SimTool will utilize state-of-the-art user interface graphics technologies to provide a high-level "point-and-click" interface to construct and operate large, complex simulations. A user of this tool constructs a simulation from a library of math models in a high-level graphical form. SimTool then integrates the selected math models via automatic code generation techniques. This same graphical representation is also used to access math model data for simulation operations. Figure 1 is a sample of the prototype (Phase I) user interface.

SimTool will catalog and organize math model interface, domain, and run-time data knowledge in an imbedded commercial data base management system. The imbedded data base management system is used to store captured knowledge, math model specifications, and all simulation data. SimTool will draw upon the captured knowledge to ensure that users construct simulations from math models that have compatible interfaces and domains.

The goal of SimTool is to provide simulation engineers with an effective tool that promotes modularity and reuse of simulation software in an environment that is easy to learn and simple to use.

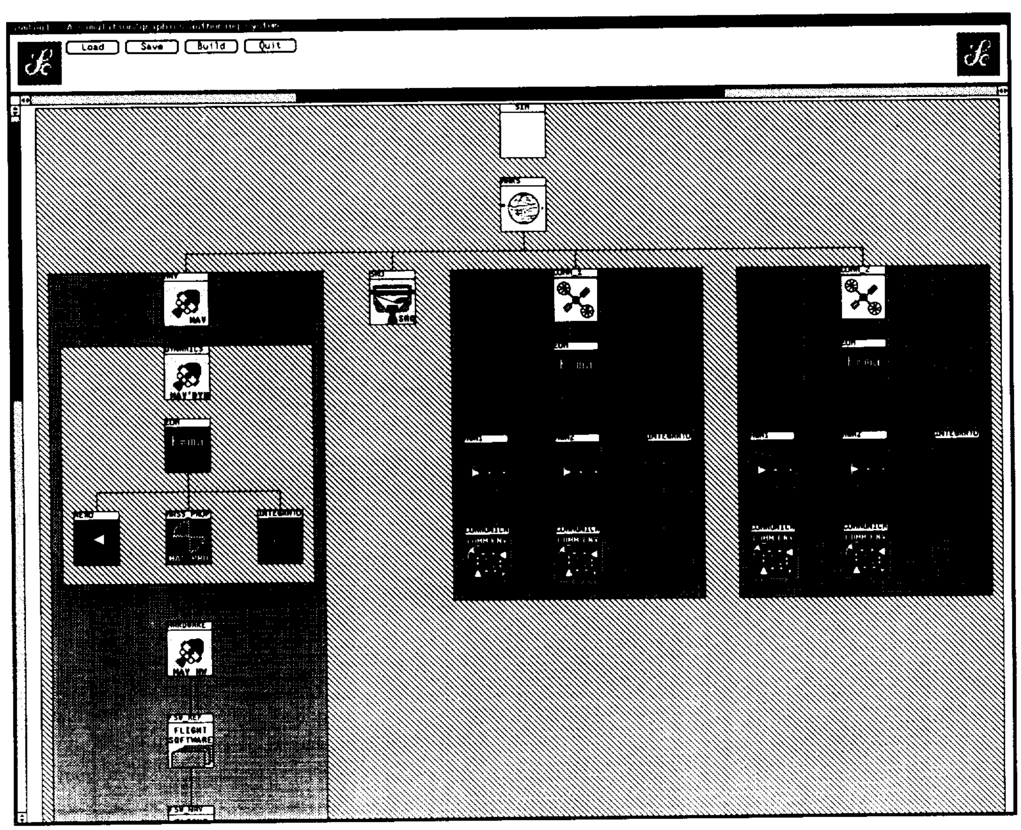


Figure 1. A sample display from SimTool showing a Mars environment, a Mars Ascent Vehicle, a Sample Return Orbiter, two communication satellites, and some of their subsystems.

NASA Electronic Library System

PI: **Ernest M. Fridge III/PT4**
Mark Rorvig/PT4
Reference: **HST 39**

The NASA Electronic Library System (NELS) is a software system that catalogs, retrieves, and manipulates information in a distributed, heterogeneous computer environment. It provides an object-oriented, X-Window system interface for managing on-line and off-line objects, including program source code, graphic images, documents, design drawings, and data in many other formats. Users can easily browse the library contents by topic, without concern for physical location of the objects, operating system differences, or object format. Descriptive information about each object can be stored and displayed by the system, and objects can be copied to the user's workstation for reuse. Advanced information retrieval functions are provided, including a natural language interface. The system supports UNIX workstations, personal computers, Macintosh, and other user nodes. Computer programs can be installed in the library to run on remote machines, if desired, to provide a friendly distributed operating framework.

The NELS effort was motivated by the desire to decrease system development costs by promoting the reuse of existing products. Before building a new object, the library can be searched for the existence of an object of the same or similar function.

Since its initial release as AutoLib (Automated Online Library System) in 1987, the NELS system has proved to be extremely useful for integrating capabilities of dispersed organizations over wide-area networks. The distributed nature of the system supports local autonomy, while maintaining a high degree of resource sharing.

During the past year, many enhancements have been added to the system; the current production release is NELS Version 1.0. New capability includes support for several graphic formats including TIFF, GIF, Raster, and Interleaf. Distributed configuration management functions and many new security features have also been introduced. Work has been completed with Version 1.0 to incorporate the Open Software Foundation Motif interface standard. An alternate VT100 Terminal Emulation feature has also been provided to support text-oriented workstations.

The benefits introduced by NELS are many. Large, distributed organizations can manage their information resources better. Productivity is increased by reducing dependency on humans for locating information and products. Users do not have to be trained on multiple computers and operating systems. Products can migrate between hardware platforms, when convenient, without changing the user interface. Redundancy can be managed better since products can be shared across multi-vendor platforms. And most importantly, NELS provides cost savings by promoting the reuse of existing resources.

Software Development Cost Estimation Model for Space Station Freedom

PI: Bernie Roush/PT4
Bill Reinl/PT4
Reference: HST 40

The development of computer software is projected to be one of the largest single-cost items associated with the development of Space Station Freedom. It is considered essential that NASA have available a means of estimating the effort and schedule required to develop a software product.

Several mathematical models have been constructed over the last decade that perform this function. The most widely used of these models is the COnstructive COst MOdel (COCOMO), developed in 1979 by Dr. Barry Boehm. Another is the "Keep It Simple, Stupid" (KISS) model, a simplified linear model developed at Johnson Space Center (JSC) using cost data derived from past NASA projects. An automated implementation of these two models has been developed at JSC for use on Space Station Freedom software.

Since the COCOMO model is over 10 years old, significant advances have been made in software engineering and the technology of developing and managing computer software since the model was developed. NASA is in the process of moving toward a software development environment where much of the new software will be developed using the Ada programming language using modern software engineering practices. It is therefore necessary to update the model to reflect the changes in software development productivity that can be anticipated in this environment.

COSTMODL, the JSC automated software cost estimation tool, was initially developed in FY87 and has been expanded to include the latest enhancements to the COCOMO model. These enhancements are specifically designed to accommodate changes in programmer productivity resulting from the development of software in Ada using the latest in software engineering techniques. However, any model must be calibrated for the specific type of software developed by a particular organization, as well as the development environment that exists within that organization. To accomplish the required calibration, a data base was constructed that contains productivity data derived from completed aerospace projects developed using the Ada programming language.

Due to the small number of Ada projects that have actually been completed and the small number of those projects for which good productivity data was captured, usable calibration data are very sparse. The total data base contains data for 741 non-Ada projects and 91 Ada projects. This is the largest currently available data base that has been compiled specifically for the purpose of calibrating the COCOMO model for aerospace projects in an Ada environment.

Using the calibrated Ada model, COSTMODL can predict the effort required to complete the projects that make up the calibration data base within 20% of the actual effort for more than 60% of the cases.

This work has been of considerable interest to the software cost-estimating community, and has resulted in several invited presentations to conferences both here and abroad. The calibrated COSTMODL program and the accompanying calibration data base are being made available to Government agencies and their contractors. In addition, COSTMODL has been submitted to the NASA Computer Software Management and Information Center for dissemination into the private sector.

Due to the fact that a model can only be calibrated with data from completed projects, it is important that the calibration data base continue to be developed as more projects are completed. The COSTMODL program and the associated calibration data base will continue to be refined and expanded as advances are made in software engineering methodologies, and as additional projects are completed using the Ada programming language.

NETS: A Tool for the Development and Delivery of Neural Networks

PI: R. Shelton/PT4
Reference: HST 41

NETS is a neural network simulator developed by the Software Technology Branch of the Information Systems Directorate at NASA/Johnson Space Center. It is possible with NETS to create and execute arbitrary configurations of neural networks that use the "back propagation" learning technique. NETS is portable and will run on a variety of platforms from super computers to desktop machines.

With the next release of NETS (version 3.0), the most significant addition is the Macintosh graphical user interface (GUI) shown in figures 1 and 2. This feature is especially important for a software product that includes technical concepts that may be new to most users. The GUI provides feedback to the user so that the time required to understand the software is significantly reduced. There is also a capability to provide a graphical display of the dynamics of the learning process. Such a display can be extremely useful as a tool for debugging and/or problem formulation.

Another kind of capability frequently needed by users involves interface to real-world applications. Due to the mathematics of the network algorithm, the numerical values produced by NETS are constrained to lie in a normalized interval ($0 < x < 1$). To integrate NETS into applications with unnormalized data, it was necessary for the user to provide a scaling algorithm. Such an algorithm is now a built-in feature of NETS 3.0. This normalization algorithm may be applied directly to the NETS data, or it may be used as a stand-alone utility for treating data for any application.

As neural networks are used more extensively, users are increasingly aware of issues of verification and validation of their neural networks. Although verification and validation of neural networks is a new area and the best methods are likely to be problem-dependent, NETS 3.0 includes an option for a generic error-testing procedure. This option allows testing of a neural network on new data (data distinct from that used to train the network) and reports maximum and root-mean-square errors on the test set. NETS is free to NASA and its contractors, and may be obtained by calling the STB Help Desk at (713) 280-2233. NETS may also be purchased by the general public through NASA Computer Software Management and Information Center at (404) 542-3265.

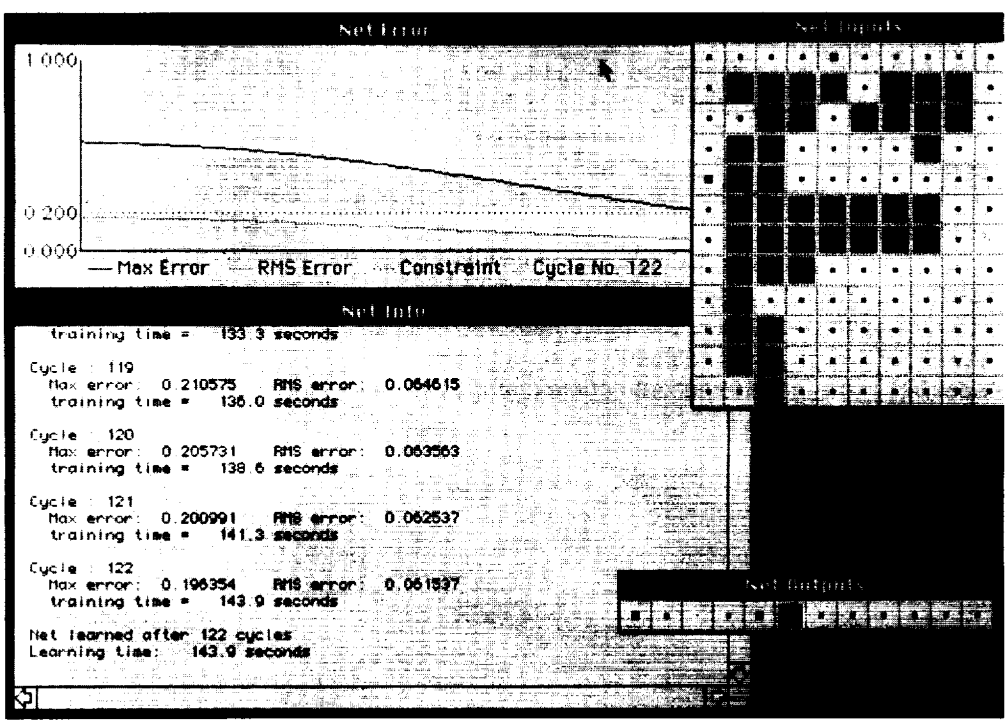


Figure 1. The NETS Macintosh graphical user interface.

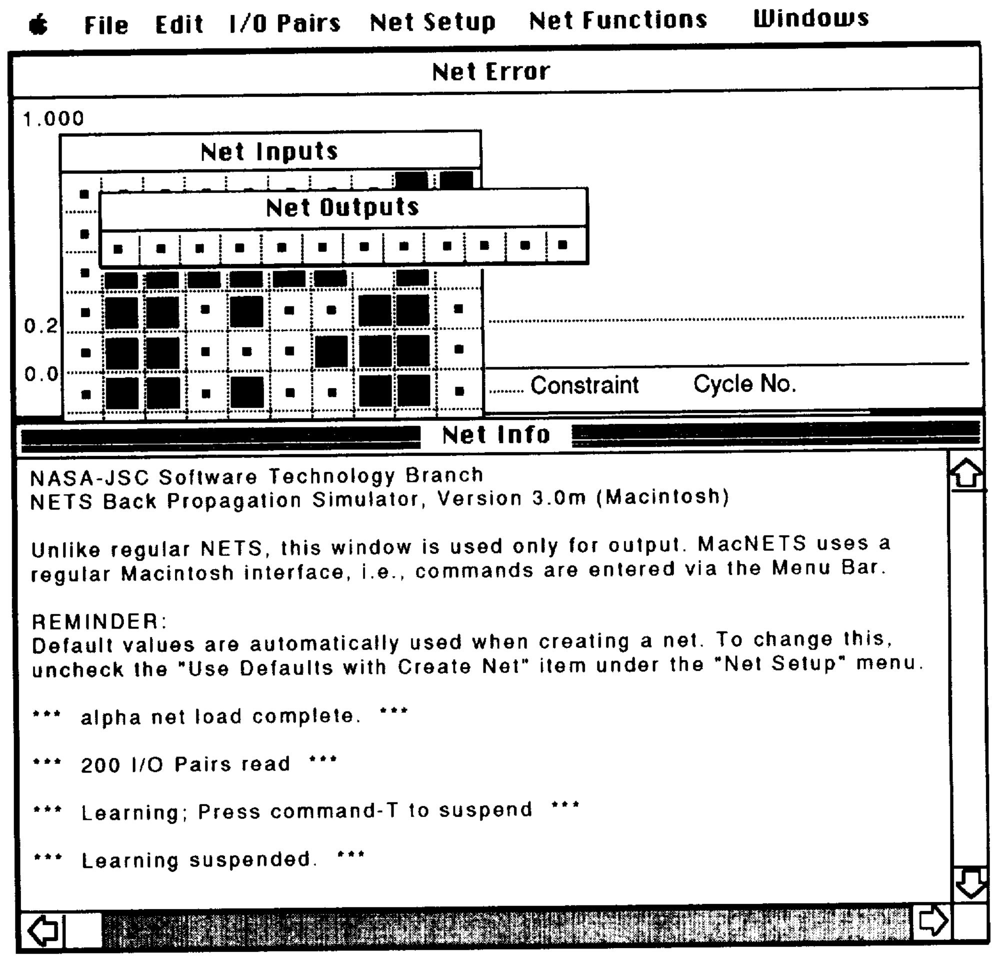


Figure 2. Another view of the NETS Macintosh graphical user interface.

Parametric Avalanche

PI: **R. Shelton/PT4**
R. Dawes/Martingale
Reference: **HST 42**

The parametric avalanche (PA) neural network was introduced by the principal investigator in 1988. This network paradigm is composed of two clusters of nodes or neurons that are interconnected by adjustable synaptic weights that encode learned knowledge acquired automatically during operation of the network. The PA differs from most network architectures in that it is designed to learn the behavior of continuous dynamical systems by exposure to example trajectories of such systems. Once the dynamics are encoded in the synaptic weights, this knowledge can be exploited to accomplish short-term prediction, which, among other things, can be used to exercise effective adaptive control.

Use of the PA as a control module for a highly nonlinear dynamical system was first demonstrated in the research sponsored as a Phase I Small Business Innovative Research (SBIR) grant awarded to Martingale Research Corporation of Allen, Texas. A prototype PA controller was constructed to maintain control of an inverted pendulum. The inverted pendulum, or so-called "cart-pole" problem, is known to be extremely difficult to solve with an adaptive or learning controller. The difficulty arises from the fact that most network-based control systems do not provide explicitly for encoding the dynamics of the system but, rather, learn patterns of associations between discrete system states. The PA proved to be an extremely effective controller for this problem. The PA was able to learn to control the system without allowing the pendulum to fall. After the system achieved equilibrium, the controller proved capable of recovery from random perturbations that were of sufficient magnitude and frequency to carry the pendulum well away from the linear range of control; e.g., maximum displacements of more than 70° from vertical.

These impressive results motivated the award of a Phase II (NAS 9-18355) continuation of the SBIR grant. The goal of the second phase is to develop a general adaptive controller for complex dynamical systems based on the PA architecture. The particular system chosen as the first demonstration arena for this technology is the control of tethered satellites. A prototype version of the system has been built that will simulate and control a satellite modeled as a massless rigid tether. The results of this work are as encouraging as the initial "cart-pole" studies. The current thrust of the work is to (1) host realistic (bead model) simulation software on high-performance platforms; (2) make such modifications as prove necessary to the control architecture based on deficiencies discovered resulting from the introduction of more realistic and, therefore, less easily controlled simulations; and (3) include perturbations such as plume effects, electromagnetic forces, and atmospheric drag.

Adaptive Control of a Robot Arm Using an Artificial Neural Net with Stereo Vision Input

PI: **Timothy F. Cleghorn, Ph.D./PT41**
Reference: **HST 43**

The mode of operation currently proposed for space and planetary surface robotics is teleoperation. While this may prove satisfactory for tasks in the immediate vicinity of a manned spacecraft, it is clear that there will be numerous occasions for which more autonomous robotic behavior will be required. Examples of such tasks include satellite servicing, for which the transmission time delays are unacceptable; routine inspections, requiring intense human concentration for long periods, thus raising the probability of error due to fatigue or boredom; and planetary surface rover operations for which the round-trip transmission times exceed the real-time requirements.

Tasks of these sorts have been addressed, usually by what can be called "automatic" robotics; i.e., the arm or vehicle is preprogrammed to carry out a specific operation. The robotic has little or no sense of environment, and if an unanticipated event occurs, at best it shuts off and waits for a human to restart it. What will be needed to carry out the more demanding tasks is the development of "autonomous" robotics in which the computer attached to the arm or vehicle has a wealth of sensory input about the environment and the ability to respond to that input without human intervention. The system thus adapts to the environment and can continue to function in the face of unforeseen events or obstacles.

Until recently, two major factors have limited the development of autonomous robotics. The first of these was the lack of sufficient computing power. This is no longer seen as a limiting problem, especially with the advent of parallel architectures. Even serial computers are now becoming fast enough, and have sufficient memory and storage capabilities to handle some of these problems. The other limiting factor was the lack of success of the "classical" artificial intelligence techniques. Combinatorial explosions usually derailed the attempts to teach computers about their environments. With the rediscovery and development of artificial neural net technology in the 1980s, this problem is also being addressed. One class of network, Adaptive Resonance Theory (ART), is particularly suitable for the environment sensing and response problem.

A simulation has been developed on a Silicon Graphics computer, which demonstrates a Robotics Research Corporation K-1607 robot arm learning to reach out and grasp a cylindrical or spherical target object. The learning process occurs with an ART-like net similar to one developed by Symbus Technologies, Inc. (formerly Neurogen, Inc.), for a Microbot arm. The inputs to these networks are stereo images of the target and arm. There are two phases: a learning phase and a production phase. During the learning phase, the arm manipulates the target cylinder or sphere within the field of view of the cameras, similarly to how babies observe their hands moving in front of their face. This allows the weights of the neural net to make an association between the camera views and the robot arm joint motions. During the production phase, the target is placed at random within the field of view of the cameras; and, depending upon the degree of learning, the arm reaches out and grasps it. The system is adaptive. During the production phase, when a successful grasp is attained, the weights are updated to reflect that particular motion. Thus the system continues to learn during this phase as well. It was found that initially learning occurred quite rapidly. After about 20,000 learning manipulations, the arm could touch the target in more than half of its attempts. The system continued to learn less rapidly for up to 200,000 manipulations, at which point it was able to touch a randomly placed target more than 90% of the time. The time needed for 200,000 learning trials was about 10 hours.

This demonstrates the potential for neural network technology for solving problems involving unstructured or dynamic environments, as are likely to be encountered in both space and planetary surface robotics operations.

Fuzzy Cognitive Maps for Mission Planning and Flight Control

PI:	**Robert N. Lea/PT4**
	Dennis Toms/TACAN Corp.
Reference:	**HST 44**

This task addresses a very important problem of planning and control that is applicable to monitoring, diagnosis, prediction, real-time decision making, and contingency planning. The fuzzy cognitive map (FCM) approach had not been considered prior to TACAN's Phase I Small Business Innovative Research study, and early results indicate the approach to be very feasible and very likely to give excellent results. This approach has certain advantages over an expert systems approach such as adaptiveness, parallel processing, combining information from different experts or sources, and ease of incorporating fuzzy logic inferencing into the system. The FCM approach also has some disadvantages such as the inability to be able to explain its responses. The FCM approach, however, should be valuable in problems of interfacing with and supplementing other knowledge-representation techniques.

As this project progresses, this methodology should find applications in diagnosis and contingency planning for the Space Station rotary fluid management pump (RFMP). This technique should be especially useful for the RFMP project because of its predictive capabilities.

Furthermore, it is anticipated that the FCM concept can be useful at NASA/Johnson Space Center in two current projects. First, it can be applied to planning and scheduling. These new methodologies can be integrated into our planning and scheduling tool, COMPASS. Secondly, but equally important, FCM can be used in a wide variety of diagnosis problems that require predictive future system states. The predicted state can be classified and decisions and corrective actions may be made to relieve the problem prior to occurrence. Tasks such as Space Shuttle main engine and auxiliary power unit diagnosis are primary candidate application areas for the FCM.

The results of this study should be generally applicable to any complex system for planning and control that requires expert knowledge for effective and stable operation. Potential commercial applications include smart robotic control, reactor and plant control, and automated manufacturing.

Fuzzy-CLIPS: The C Language Integrated Production System with Fuzzy Logic Capability

PI:	**Robert N. Lea/PT4**
	Yashvant Jani/Togai Infralogic
	Jack Aldridge/Togai Infralogic
Reference:	**HST 45**

During Phase I of this Small Business Innovative Research (SBIR) program, Togai InfraLogic demonstrated a unique expert system development environment that combines conventional symbolic processing capabilities of NASA/Johnson Space Center C Language Integrated Production Syste (CLIPS) with a fuzzy logic-based approximate reasoning capability. No commercial software tool of this type currently exists that allows the development of fuzzy logic systems within the framework of a conventional expert system shell.

In Phase II of this SBIR, the prototype is being enhanced by extending options for inferencing and defuzzification, supporting multiple outputs from the fuzzy rule base and providing verification and validation capability to evaluate the rule base. Togai Infralogic will add a generalized differential competitive learning capability that can greatly assist in developing rule bases and membership functions and a means to store fuzzy rules in C code representation for developing a run-time version.

Combination of fuzzy logic and CLIPS will empower CLIPS users with a cohesive, leading edge artificial intelligence tool. The architecture (fig. 1) will give CLIPS users a new dimension in expert system development with minimal learning time impact for development of fuzzy logic systems. Such a tool with fuzzy/symbolic computation capability can be applied to flight planning and control, risk analysis, intelligent data fusion and interpretation, heuristic pattern recognition, and diagnostic systems. The fuzzy-CLIPS product should be particularly useful in the area of system diagnostics where, currently, the problem of integrating uncertainty into such systems has received little attention.

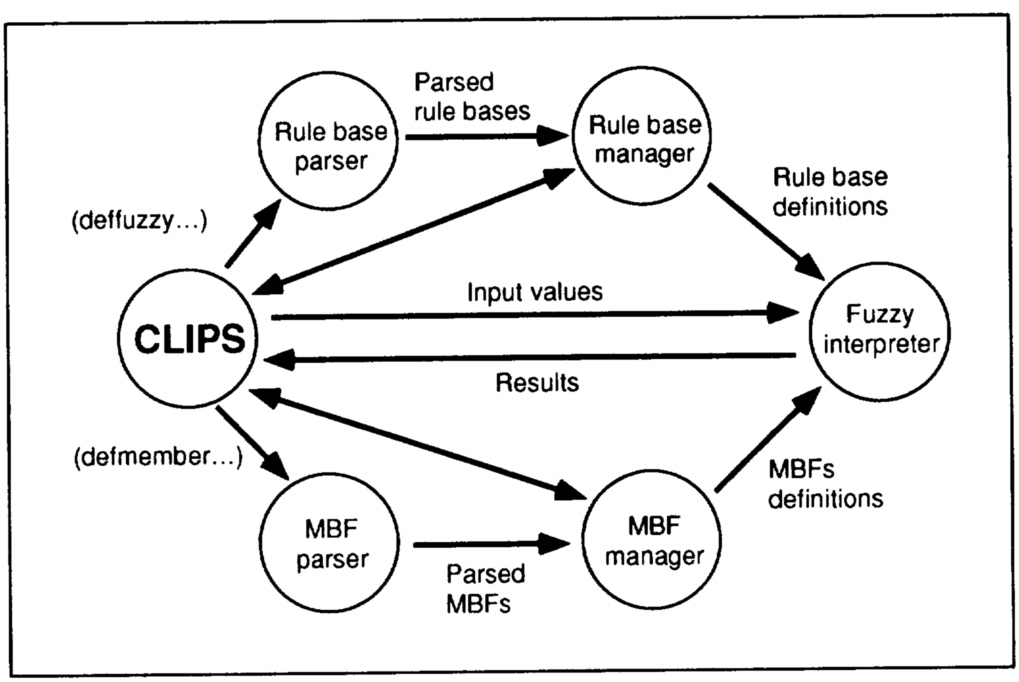


Figure 1. Fuzzy-CLIPS architecture that combines fuzzy capability with CLIPS.

Fuzzy Logic for Adaptive Control and Operational Decision Making

PI: Robert N. Lea/PT4
Reference: HST 46

Future space missions will require autonomy as well as high operational efficiency to ensure effective performance. Studies at NASA/Johnson Space Center (JSC) have shown that fuzzy logic technology is powerful and robust in interpreting imprecise measurements and generating appropriate control decisions in expert systems applications. JSC has set objectives of developing applications of fuzzy logic to control of space vehicles and remote manipulator systems, and developing an adaptive logic design to create more robust fuzzy controllers.

As a first step towards the development of an intelligent sensor system, a camera tracking controller was designed and fuzzy logic-based rules were developed and coded using the TILShell and fuzzy-C compiler. The fuzzy controller receives the position of the object in terms of pixel location in the camera field of view and range from a laser range finder. Commands for the pan and tilt gimble drives are generated using the rule base with 35 fuzzy rules. A relative trajectory software simulation was developed to test the performance of the tracking controller during proximity operations. Seven test cases are designed to simulate representative trajectories between two spacecraft. Results show that the tracking controller performance is very good. It is able to track the object and keep it in the field of view for seven test cases. These results will be presented at the FUZZ-IEEE meeting during March 1992. The camera tracking controller operationally provides an advantage because it easily adapts to any motion of an object in the field of view and is not constrained to any presumed trajectory.

A fuzzy logic-based tether length controller was designed and implemented in the Orbital Operations Simulator that simulates the tethered satellite system (TSS) mission including deployment and retrieval phases. The simulation has a tether model with finite mass, 6 degree-of-freedom (DOF) Space Shuttle, and 6 DOF Italian satellite model with respective attitude control systems. The fuzzy controller has two inputs: length and length rate error. Output of the fuzzy controller is the required change in voltage that is added to the guidance desired voltage.

The fuzzy controller was compared with the baseline TSS-1 mission controller using massless as well as finite mass tether models. The length and tension errors were reduced during the entire mission, especially during the retrieval phase. Results on the massless tether model were presented at the North American Fuzzy Information Processing Society meeting in May 1991. The results with finite mass tether model will be presented at the FUZZ-IEEE meeting in March 1992. It is significant to note that the transition from the deployment to the on-station phase as well as from on-station to retrieval phase is very smooth in the case of the fuzzy controller. Because of better length control and reduced tension oscillations, significant improvements are observed in the librational oscillations when the tether is retrieved from 20 km to 2.4 km. As shown in figure 1, the librational amplitude is 12° in the case of the baseline controller. For the case of the fuzzy controller, it is reduced to 4.5°.

The fuzzy logic-based attitude controller was combined with the translational controller that utilizes fuzzy rules based on crew procedures. This combined 6 DOF controller was tested in the orbital operations simulator using V-bar, R-bar, stationkeeping, and fly-around test cases. Our results show that the fuzzy controller performance is very good and is comparable to other man-in-the-loop simulation results. All operations are performed within the guidelines and constraints for the mission. Our results indicate that a future unmanned spacecraft with similar capability will be able to perform automated proximity operations. These results were presented at the AIAA Guidance, Navigation and Control conference at New Orleans in August 1991.

The fuzzy logic-based attitude controller developed for Space Shuttle during FY90 was integrated with the reinforcement learning technique developed at NASA/Ames Research Center. This fuzzy logic and neural network-based learning technique is applied to learn and perform attitude operations during the proximity and docking phase of the mission. A high-fidelity Shuttle simulation is being used to test the performance of this fuzzy neural control system. Preliminary test results indicate that learning can be achieved so that unknown orbital perturbations can be handled.

The main objective of FY91 activities has been to utilize fuzzy logic for adaptive control and decision making and to increase autonomy in orbital operations. Greater autonomy desired for future space operations will result in a higher level of operational efficiency. Results obtained over the last few years promise a very successful utilization of fuzzy logic in autonomous orbital operations.

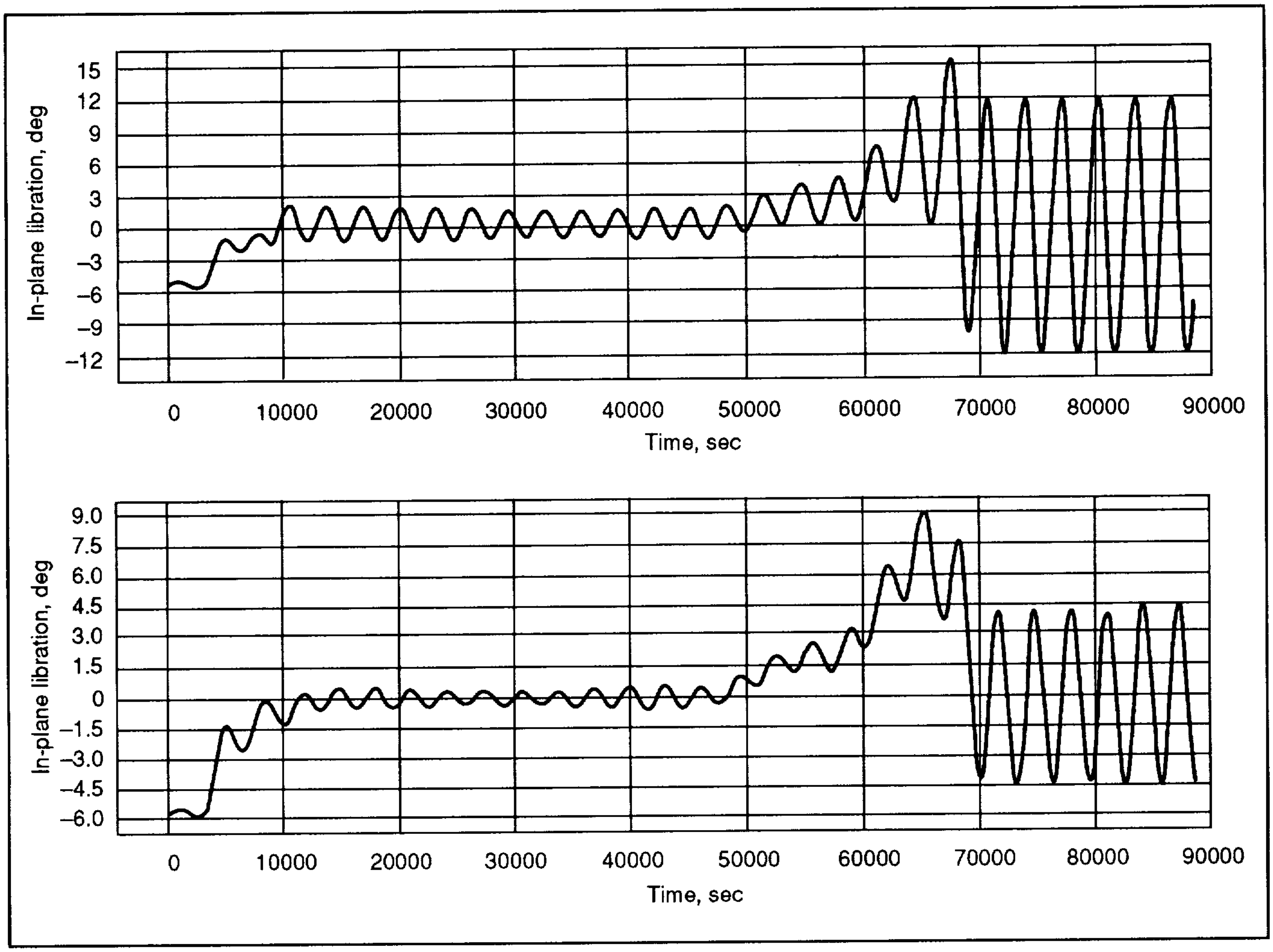


Figure 1. Librational angle magnitudes during tether retrieval from 20 km to 2.4 km. (Top figure shows angle for baseline control finite element tether model in TSS simulation. Bottom figure shows angle for fuzzy control finite element tether model in TSS simulation.)

Knowledge-Based System Verification and Validation

PI: **Chris Culbert/PT4**
Reference: **HST 47**

Knowledge-based systems (KBSs) are in general use in a wide variety of domains. As reliance on these types of systems grows, the need to assess their quality and validity reaches critical importance. As with any software, the reliability of a KBS can be directly attributed to the application of disciplined programming and testing practices throughout the life cycle (fig. 1). However, there are essential differences between conventional software and knowledge-based systems, both in construction and use. The identification of how these differences affect the verification and validation (V&V) process and the development of techniques to handle them is the basis of work in this field.

Much of the work in KBS V&V has focused on developing conceptual approaches and postulating different techniques for performing some or all aspects of V&V on various types of KBSs or expert systems. Very little work in this field has demonstrated the usefulness of proposed techniques on operational KBSs. Even more importantly, since effective V&V must be applied throughout the life cycle, there has been almost no case study work in applying disciplined software V&V principles throughout the development of an operational KBS. The long-term goal of the project is to develop guidelines, standards, tools, and techniques for V&V of all KBS applications that may be used in the Space Station Freedom Program or other NASA programs. As a precursor to determining the applicability or usefulness of many of the proposed KBS V&V techniques, it is important to develop an understanding of what V&V practices are commonly in use today and how proposed techniques can improve upon those practices. During FY90, the Software Technology Branch and their support contractor, IBM, reported on a survey documenting the experiences and problems KBS developers have encountered in performing V&V on their systems and related those problems to the kinds of issues KBS V&V researchers consider important. The results of the survey and selected follow-up interviews suggested a number of specific conclusions and directions for further work in this field based upon the kinds of problems that developers have really encountered in developing and verifying expert systems.

During FY91, work began on developing a set of guidelines for KBS verification and validation that would specifically address many of the problems the previous survey work had raised. These guidelines were structured to provide KBS developers throughout NASA basic information about the issues associated with determining the validity of expert systems and to give them an initial set of techniques, which could be tailored to their specific system needs. These guidelines, which will be completed in early FY92, will be taught through a hands-on training course and eventually made available in document form and through computer-based training.

In future work, these guidelines will be evaluated in terms of the needs of those NASA programs that can readily use KBS technology, such as the Space Station Freedom and the Space Transportation System. They can then be tailored to the needs of a specific program and improved to correct new problems as they are discovered. Other work will be aimed at developing specific programs and practices that improve the quality of KBS used in all NASA programs.

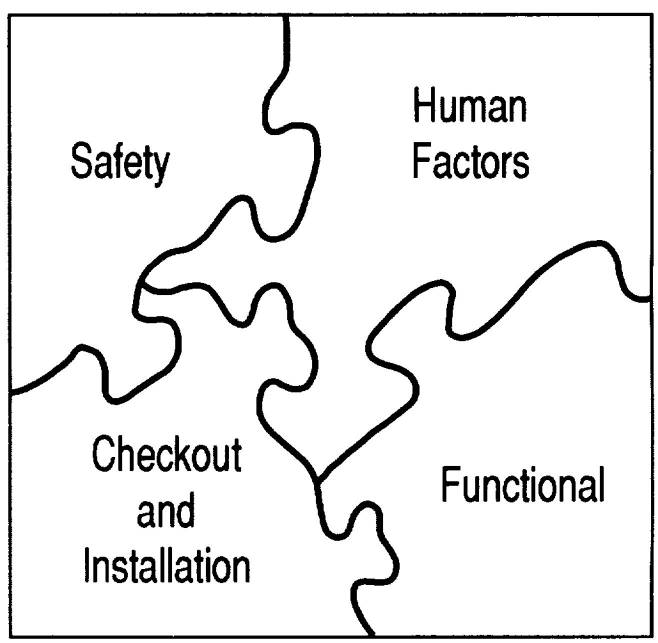


Figure 1. The verification puzzle.

Cooperating Expert Systems

PI: **Chris Culbert/PT4**
Reference: **HST 48**

Knowledge-based system technologies have successfully bridged the growing gap between low-level control systems and human control in narrow applications. Although only a few have been integrated into the domain of spacecraft operations, many applied research projects have shown that knowledge-based systems can provide human workload relief and are able to perform routine operations for individual spacecraft systems. True integration, however, cannot be achieved by simply attaching a knowledge-based controller to every subsystem. As demonstrated by current ground mission control operations, communication and cooperation among controllers is a mandatory requirement for a robust control organization. Coordination among knowledge-based, human, or heterogeneous controllers requires a body design and implementation guidelines that are still under development.

The purpose of this project is to define and develop guidelines, methodologies, and tools for distributed cooperating systems, and to apply them to develop and deliver distributed and cooperative systems tools to interested customers.

Although cooperation can be achieved in many different ways, there are two primary architectures for cooperation: hierarchies and peer committees. Each approach has advantages and disadvantages. On the pro side, a hierarchical organization provides centralized locations to define overall system behavior. It provides a natural partition to organize knowledge that is relevant to two or more systems simultaneously. It simplifies the human-machine interface. However, a hierarchical organization is also a single point of failure and a potential communications bottleneck. A hierarchical pyramid of agents might waste resources in vertical communications and subsequent processing. For a peer committee organization, the advantages include providing flexibility for reconfiguration under changing mission requirements and for evolutionary development during a spacecraft life cycle. It can function as a hierarchy if necessary. However, a peer committee organization might lack the ability to guarantee reasonable upper bounds in decision-making processing and might waste resources in unending goal refinement.

Before FY90, two expert systems were developed, which could be used to evaluate cooperative, distributed systems issues. During FY90, these systems were put into a distributed, cooperative test-bed that focused on evaluating a hierarchical organization of cooperating expert systems.

During FY91, distributed system features from the test-bed were applied to improve elements of real-time data system in the Mission Control Center. This new version has already worked through three Shuttle flights. The Space Station era will require even more powerful and flexible data distribution systems. Current work uses the CoopES test-bed to implement and study distributed, adaptive control techniques. These new techniques will be the keystone of future control center capabilities. Distributed control agents will support self-organizing data distribution networks with automatic load balancing.

Separate studies on distributed scheduling show that major issues remain to be solved. In particular, practical experiments under development will provide insights into protocols to coordinate human scheduler actions and improve schedule quality. Distributed support packages have been built and other groups have used them in their own work. In particular, these products are part of an ongoing distributed simulator study. All this work relies entirely on standard tools (UNIX, C, and CLIPS) and approaches (object-oriented design and protocols). More experimental languages such as Lips are no longer present in the system. All CoopES software runs across a wide range of UNIX platforms (Sun, Masscomp, DEC, and IRIS).

Solar System Sciences

Summary

Solar System Sciences

Research at the NASA/Johnson Space Center (JSC) in Solar System Sciences during the past fiscal year (FY91) has covered a number of disciplines. This necessarily has been broad in scope and varying in its relationship to science as a centerpiece of many of the current NASA initiatives in space. It includes new investigations of

- Meteorites
- Cosmic and planetary dust
- Earth orbital debris
- Remote sensing of Earth
- Space radiation environment
- Analysis of lunar and planetary material
- Origin and evolution of planetary structure

Highlights of new accomplishments in FY91 include (1) development of space science experiments for planetary exploration; (2) development of instrument technology for lunar and planetary missions; (3) experimental measurement and modeling of the low Earth orbit debris environment; (4) development of debris countermeasures; and (5) geological and geochemical research on the nature, origin, and evolution of the solar system.

Naturally, this work is intended to support a fundamental space research program in Earth orbit, as well as a planetary exploration program having goals that include establishment of a lunar outpost and possibly a human mission to Mars.

The following, though not comprehensive, is a limited presentation of some of these investigations.

Does Water Exist on Mars?

Planetary sample missions may include future unmanned landers that analyze the surface of a planet and, conceivably, return samples back to Earth for examination in NASA laboratories. Such a mission could certainly be to Mars, partially for its experimental significance to planetary science and partially because Mars may be an eventual goal of the Agency Space Exploration Initiative (SEI) beyond a lunar outpost.

Critical for any human initiative in space exploration is the search for water—a practical source of water. Coupled with the intriguing question of the existence of water on Mars is the interesting hypothesis that certain water-bearing meteorites originated on Mars. Two JSC studies of this question are presented.

Cosmic Dust and Hazardous Debris

Cosmic dust is a critical component of our solar system that has undergone years of experimental study at JSC. This includes the return last year of the Long-Duration Exposure Facility and stratospheric dust collection with NASA aircraft.

Sources of this dust include comets, asteriods, and interstellar matter. The scientific benefit of cosmic dust analysis supplements research on the significance of collisional impacts from orbital debris in Earth orbit. JSC has attempted to establish a thorough program in hypervelocity impact analysis so both science and space operations can benefit from this work.

Reported here is an example of a scientific experimental study on the morphological character of hypervelocity impacts. This work supports the NASA analysis of meteoroid shielding techniques, materials, and geometries for long-duration human presence in space.

Orbital Debris

Also reported is a study of the orbital evolution for geosynchronous Earth orbits. The motivation for this work was to gain an understanding of the potential for man-made debris collision hazards in Earth orbit created by a preponderance of geosynchronous satellites. A trade study of geosynchronous versus non-geosynchronous satellites is discussed as well as the impact on ground operations.

Pneumatic Conveyance in Reduced Gravity

Use of *in situ* planetary resources is an issue related to any practical strategy for the human exploration of space. The long-term viability of a manned lunar outpost, for example, is dependent upon engineering considerations for constructing such a habitat. Yet, the technology of such a venture in space is basically unknown, since the behavior of many Earth-adapted processes has never been established in partial gravity such as that of the Moon.

An example is the movement of regolith at a lunar base. To this end, studies using artificially induced weightlessness in NASA aircraft are being conducted. Presented here is one such analysis that focuses on the transport of lunar soil simulant in partial gravity.

Space Radiation Environment

The effect of space radiation upon human beings represents an important limiting factor or constraint in manned spaceflights. This is manifest as a radiation dose limit, which is reflected in career limits for NASA astronauts. Flight duration and radiation exposure, in turn, have a great deal to do with the planning for long-duration missions, as well as design of habitation quarters for a permanent lunar outpost and spacecraft design for manned missions to Mars.

Reported here are new results from phantom head dosimetry measurements taken on board the Space Shuttle. These, in conjunction with computer model analysis, enhance our understanding of the radiation fluxes encountered on the flights. The latter will aid considerably in mission planning for Space Station Freedom and SEI.

Section III

Solar System Sciences

Significant Tasks

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Water-Based Chemistry in Martian Meteorites

PI: **James L. Gooding, Ph.D./SN21**
Reference: **SSS 1**

River-type valley networks and flood channels on Mars testify to an abundance of water in previous martian epochs. But did the water persist long enough to support biochemical reactions that would have been critical to the development of life? If so, what clues might the putative martian meteorites provide about the nature of water-based chemistry and the prospects for biological exploration of Mars?

Four shergottite, three nakhlite, and one chassignite meteorites comprise a geochemically and isotopically related clan of rocks that might have been ejected from Mars by one or more energetic impact-cratering events. The eight so-called SNC meteorites are divided into three sub-groups based on their similarities to the "type" specimens that fell in Shergotty (India), Nakhla (Egypt), or Chassigny (France), respectively. The direct evidence for their martian origin occurs in shergottite Elephant Moraine, Antarctica, A79001 (abbreviated as EETA79001), which contains glass inclusions with trapped atmospheric gases that are nearly identical to those in the martian atmosphere (which was independently analyzed by the Viking landers in 1976). By close material similarity with EETA79001, especially based on kindred ratios of oxygen isotopes, the other seven SNCs are also inferred to be from Mars.

Although the SNCs are volcanic rocks, most of them contain traces of volatile compounds that indicate either retention of volcanic water or later interactions with water-based solutions. Work begun at NASA/Johnson Space Center in 1985 has steadily increased the body of evidence regarding the identities and significance of these water-precipitated minerals. We have now shown that all sub-groups of SNCs contain various combinations of carbonates, sulfates, halides, ferric oxides, and aluminosilicate clays of preterrestrial origin (table I). These minerals occur only in trace concentrations; in Nakhla, for example, the entire inventory of clays and salts is probably < 0.01 wt. percent of the bulk meteorite. Typical grain sizes are 1 to 20 μm for salts and < 2 μm for clays. Accordingly, discovery and identification of these minerals have required painstaking analytical work. Even though precise identification of some of these minerals continues to present analytical challenges, enough knowledge has accrued to support useful inferences about water-based chemistry on Mars.

The case for preterrestrial origins of the subject minerals rests on microscopic analysis of critical sequence-of-events evidence. For example, salt and aluminosilicate grains are physically trapped in silicate melt pockets in shergottite EETA79001; clay-bearing veins in Nakhla are truncated by meteorite fusion crust; and salt veins in Chassigny are found in the interior of the meteorite but are never superposed on fusion crust. From superposition and cross-cutting of the secondary minerals by fusion crust, which is an unambiguous time stamp for Earth arrival, the subject minerals are clearly indicated to be of preterrestrial origin. As assemblages of water-soluable salts and hydrous clays that form veins in volcanic minerals, they are further constrained to be products of precipitation from aqueous solutions that postdated high-temperature crystallization of the host rocks (fig. 1).

The aqueous precipitates indicate that oxidizing, water-based solutions probably have been chemically active on Mars for at least the time interval represented by the radiometric ages of the meteorites, namely, the past 200 to 1300 M years. Those solutions included biogenic elements (at least H, C, O, P, and S; N not yet found among the salts), although inorganic precipitates apparently predominated over organic products. Analyses for indigenous organic compounds have mostly yielded negative results. In addition, preliminary searches for distinctive products of biomineralization have been negative. No evidence for the action of chemolithotrophic bacteria has been found, although further detailed mineralogical and stable-isotopic studies of the secondary minerals might help establish limits for biogenic activity in water-based martian chemistry over the past 1300 M years. A mixture of aqueous precipitates found in the SNCs, comprising smectite, illite, and gypsum (with minor halite ± calcite and hematite), provides a self-consistent, though not unique, model for the bulk elemental composition of surface sediments at the Viking lander sites. Among other implications, the smectite-illite model lends support to a previous hypothesis that the catalytic action of clay minerals was responsible for the surprising chemical reactivity discovered by the Viking lander biology experiments. The smectite-illite-salt model is also compatible with visible and infrared spectrophotometry of martian dust as measured by other workers using Earth-based telescopes.

Work is progressing toward the goal of documenting the aqueous geochemical history of each SNC meteorite. In advance of a Mars sample return spaceflight mission, the SNCs offer the best direct hunting ground for clues about martian water chemistry and the prospects for past or present martian living organisms.

TABLE I. WATER-PRECIPITATED MINERALS OF POSSIBLE MARTIAN ORIGIN IDENTIFIED IN SNC METEORITES

	Shergottite EETA79001	Nakhla	Chassigny
$CaCO_3$	■	■	■
Mg-bearing $CaCO_3$	■		
$MgCO_3$			■
$(Fe,Mn)CO_3$		■	
$CaSO_4 \cdot nH_2O$	■	■	■
$(Mg)_x(PO_4)_y \cdot nH_2O$	■		
$(Mg)_x(SO_4)_y \cdot nH_2O$		■	
$(Na,K)Cl$		■	
"Illite" $(K,Na,Ca_{0.5},H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,H_2O]$	■		
S,Cl-bearing micabole	■		
Smectite $(Na,Ca_{0.5})_{0.3}(Al,Mg,Fe)_{2-3}(Si,Al)_4O_{10}(OH)_2 \cdot nH_2O$		■	
$Fe_2O_3 \cdot nH_2O$		■	

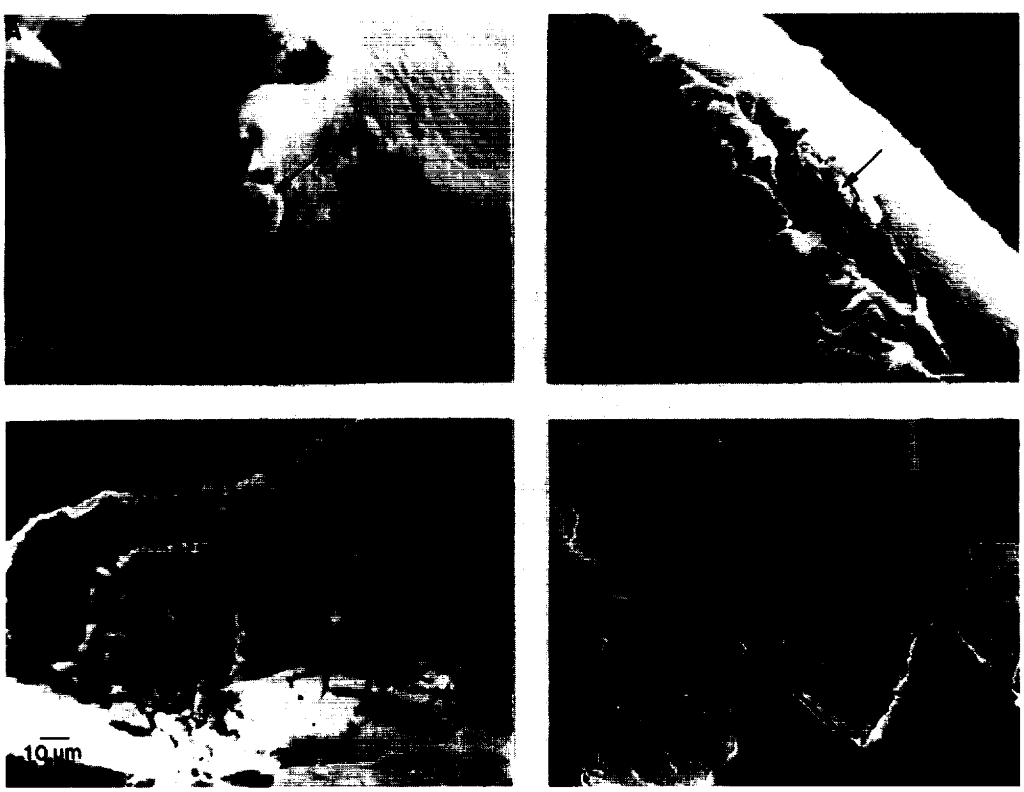

Figure 1. Scanning electron photomicrographs of water-precipitated minerals (marked by arrows) in Nakhla meteorite. (A), (B) Calcium carbonate. (C) Magnesium sulfate. (D) Calcium sulfate (blocky grains) and smectite-bearing clay (amoeboid vein). These minerals indicate that this rock chemically reacted with water on its parent planet, which, on independent grounds, is believed to be Mars.

Martian Water: First Direct Analysis in a Terrestrial Laboratory?

PI: **Everett K. Gibson, Ph.D./SN2**
Haraldur R. Karlsson, Ph.D./NRC
Reference: **SSS 2**

Existing evidence suggests that the planet Mars once had a water-rich atmosphere and flowing water on its surface. At some stage in the planet's history, however, virtually all of the water vanished, leaving its surface devoid of water in liquid form. Even the atmosphere contains only minute amounts of water vapor. Because water plays a pivotal role in most geological processes, it is important to obtain further information about this ancient phenomenon for a better understanding of the geological evolution and history of Mars.

Many lines of evidence suggest that the "SNC" group of meteorites (Shergotty-Nakhla-Chassigny) are derived from the planet Mars. Because SNC meteorites have water, they may contain information on the origin and fate of water on that planet. We have measured the oxygen isotopic composition of water extracted from the SNC group of meteorites. Evidence such as young crystallization ages compared to other meteorites, as well as compositions of trapped volatiles matching those of the martian atmosphere, suggests that these objects came from Mars (fig. 1). Previous stable isotopic studies of water from SNCs have concentrated on measuring the D/H isotopic ratios using either combustion or pyrolysis techniques. The results are conflicting, and none thus far demonstrates conclusively whether the water is extraterrestrial. Our investigations concern the isotopic composition of oxygen, for which the three isotope systematics can unequivocally identify extraterrestrial material.

We have obtained the first measurements of $\delta\,^{18}O$ and $\delta\,^{17}O$ (Oxygen-18 and Oxygen-17) of water extracted from SNCs. After overnight room temperature evacuation, powdered samples of Chassigny, Lafayette, Nakhla, Shergotty, Zagami, and ALHA79001 (both lithology A and B) were heated under high vacuum, and the volatiles evolved were condensed into a cold trap at liquid nitrogen temperatures. Each sample was heated stepwise to 150°C, 350°C, 600°C, and 1000°C, and was held at those temperatures for 1 hour (fig. 2). Water was then cryogenically separated from other volatiles by raising the cold-trap temperature to that of dry ice. Water was converted to O_2 using BrF_5 and isotopically measured on a double collecting ratio mass spectrometer. Yields (weight % H_2O) were: Chassigny 0.102%, Lafayette 0.387%, Nakhla 0.114%, Zagami 0.042%, Shergotty 0.064%, and ALHA79001 (lithology A and B) 0.064%.

Previous work has shown that the SNC whole rock oxygen isotopic compositions lie on a mass fractionation line parallel to the terrestrial line on a three-isotope plot. Examination of the ^{18}O isotopic compositions of the extracted water from the SNC meteorites does not reveal the true extraterrestrial nature of the water because of the effects of terrestrial weathering and other alterations upon the samples. However, the ^{17}O isotopic compositions show clearly that there is an extraterrestrial water reservoir that has not isotopically equilibrated with the rock material of the SNC parent body. The plausible choices are either the impactor, which ejected the meteoroids from the parent, or a parent body surface reservoir (atmosphere or hydrosphere) that had evolved independently of the lithosphere. Since Nakla, the meteorite that showed the largest ^{17}O excess, is known to contain "iddingsite" as a parent-body weathering product formed at low temperature, it is probable that all the ^{17}O excess observed in water from SNCs is derived from a martian surface reservoir.

The existence of a ^{17}O excess in some of the SNC meteorites implies that at least two different oxygen isotopic reservoirs were on the SNC parent body (i.e., Mars by hypothesis). Isotopic differences have arisen during accretion of the parent body or after accretion during the evolution of the atmosphere. The most likely source of the ^{17}O excess is the hydrosphere, since the main source of water within the SNCs is weathering products. Two scenarios arise: (1) The hydrosphere and the lithosphere could have evolved separately from isotopically distinct reservoirs during accretion and remained decoupled thereafter. Many proposals for planetary accretion require separate components for the volatile-poor fraction and the volatile-rich fraction. Such components are very likely to have differed in oxygen isotopic compositions, as do meteorites of different classes. Mars, in contrast to Earth, lacks plate tectonics—the mechanism by which isotopic homogenization occurs on Earth. For example, it has been shown that the terrestrial oceans are buffered to a relatively constant oxygen isotopic composition by exchange between seawater and basalt at mid-ocean ridges where the plates are being generated. Thus, the whole ocean is cycled through the oceanic crust in a few million years, quickly erasing any isotopic anomalies that might have existed between the hydrosphere and lithosphere on Earth. (2) Alternatively, the hydrosphere on Mars initially could have been in equilibrium with the lithosphere but changed its composition over time owing to influx of isotopically distinct material such as comets. A change in the isotopic composition of the atmosphere (and hydrosphere) may also have resulted from photochemical processes leading to loss of oxygen from the planet. Some such processes are known to have anomalous oxygen isotopic behavior. Again, the two reservoirs could have remained separate in the absence of an efficient mixing mechanism such as plate tectonics.

Enrichment of the ^{17}O isotopic composition from water extracted from four SNC meteorites as compared to the oxygen extracted from the silicates portion of the whole rock meteorite samples is shown in figure 3. The 600°C and 1000°C fractions of water indicate a ^{17}O component in the water within the SNC samples, which is different from the oxygen within the silicate portion of the meteorites. This component may represent a cometary water or some other source that is present on the planet Mars.

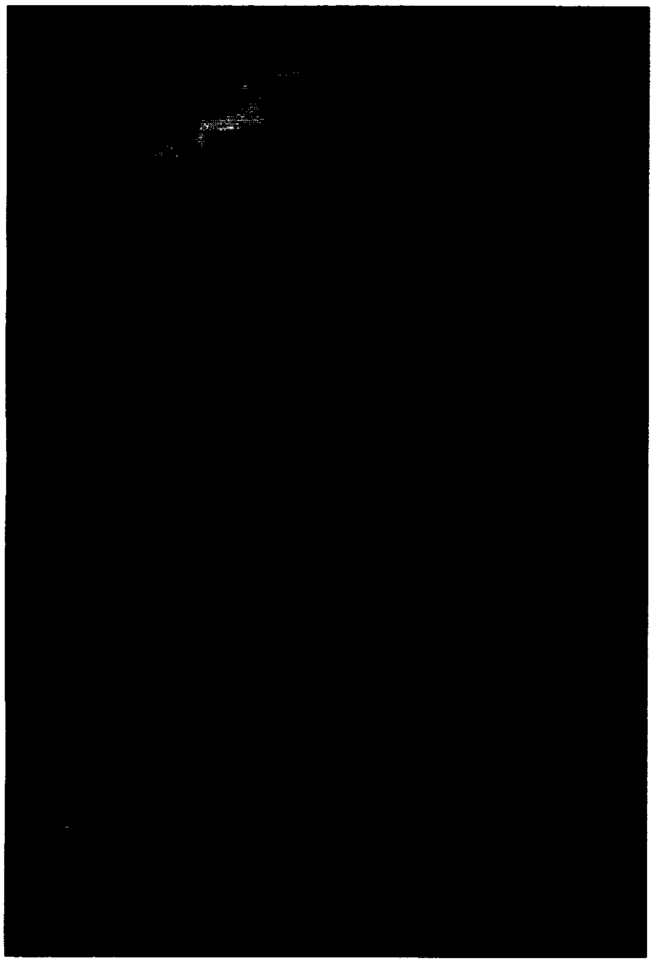

Figure 1. Mars and the SNC meteorites. It is believed that the SNC group of meteorites are from the planet Mars. The individual meteorite samples analyzed in the study are shown against their probable parent body, Mars.

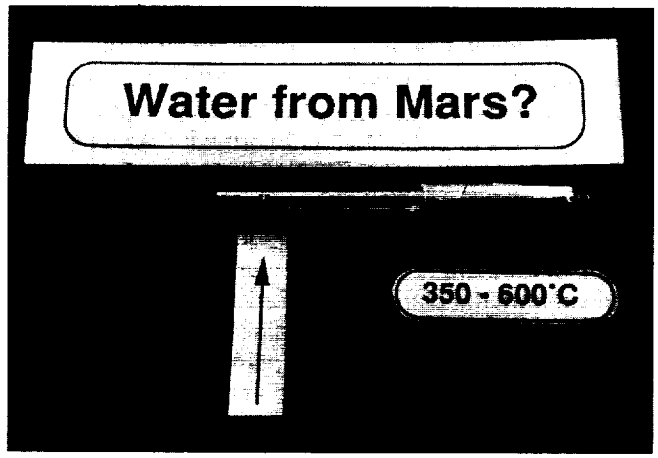

Figure 2. Sample tube showing the water droplet extracted from the Nakhla meteorite during heating between 350°C and 600°C. The water droplet has been shown to contain unusual extraterrestrial water with an enrichment in its Oxygen-17 (^{17}O) isotopic composition. The water droplet may represent a sample of martian water that had been retained by the Nakhla SNC meteorite.

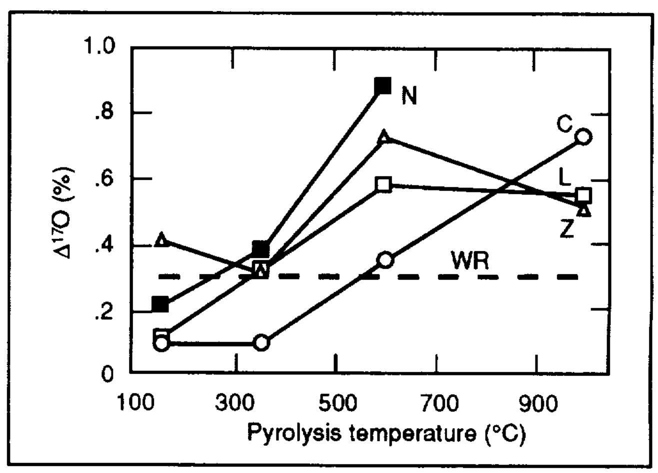

Figure 3. Enclosed figure showing Oxygen-17 (^{17}O) enrichment in the water extracted from four SNC meteorites.The symbols N, C, L, and Z represent the SNC meteorites Nakhla, Chassigny, Lafayette, and Zagami, respectively.

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Hypervelocity Penetrations of Dimensionally Scaled Targets

PI: **Friedrich Hörz, Ph.D./SN2**
Reference: **SSS 3**

The Cosmic Dust Collection Facility (CDCF) is currently undergoing development as an attached payload on board the early Space Station Freedom. The CDCF instruments will measure the trajectory of individual hypervelocity particles in low Earth orbit (LEO) and trap them in such a fashion that analyzable residues can be returned to Earth. Combining compositional information and trajectory analyses of natural, interplanetary particles must be viewed as proxy analysis of comets and asteroids. Being deployed in LEO, such instruments can also identify the sources of man-made orbital debris.

Two components, a trajectory sensor and a suitable capture medium, will compose the instruments. Both components employ thin films and require detailed understanding of penetration phenomena by hypervelocity particles. Therefore, a series of impact experiments was performed with a light gas gun that fired spherical soda-lime glass projectiles at 6 km/s into aluminum targets of variable thickness (T). The absolute thickness T may be normalized to projectile diameter (D_p) to yield the dimensionally "scaled" target thickness D_p/T. An experimental matrix utilizing dramatically different target thicknesses and associated D_p/T ratios will, thus, simulate the on-orbit conditions of exposing a foil of fixed thickness to natural and man-made particles that vary greatly in size.

Figure 1 depicts impact craters for projectiles of 50, 150, 1000, and 3200 μm diameter in infinite half-space targets and penetration holes in targets of systematically decreasing thicknesses. At $D_p/T < 1$, the penetrations in essence resemble truncated cratering events, yet hole size decreases systematically with increasing D_p/T until hole-dimensions asymptotically approach those of the impactor, typically at $D_p/T > 50$. Note the striking similarity of detailed hole morphology at any given D_p/T, regardless of absolute scale. We measured the hole diameters (D_h), and figure 2 illustrates their relationship with D_p and T. Although D_p varied by almost two orders of magnitude, the dimensionally scaled measurements combine into a single curve. This demonstrates that it is possible, in principle, to obtain unique solutions for the diameter of unknown impactors on space-exposed surfaces from simple measurements of hole diameter (D_h) and target thickness (T).

In a rigorous sense, the curve illustrated in figure 2 is valid only for silicate impactors at 6 km/s. It is known that crater diameters increase exponentially with velocity (exponent is 2/3); it is, therefore, expected that penetration holes representing truncated craters ($D_p/T < 1$ in fig. 1) will scale likewise. On the other hand, the condition of $D_h = D_p$ at very thin foils seems velocity independent; each impactor simply produces a hole mimicking its cross section, no matter what encounter speed. Experiments to verify these expectations are in progress.

The major objective of this experimentation was to establish calibration curves that permit the derivation of projectile size(s) from space-retrieved foils. Obviously, the velocity-dependent effects must be understood first to render such calibration meaningful. Nevertheless, the current effort establishes important principles and demonstrates that the simplified assumption of $D_h = D_p$, used by some, is incorrect in many cases. Note that most penetrations in thermal blankets retrieved from the Solar Maximum and Long-Duration Exposure Facility satellites have scaled dimensions of $D_h/T < 10$. The current effort also illuminates that substantial target masses are displaced during penetrations of relatively thick targets, a result that is of significance for the design of passive collisional shields ("meteoroid bumpers"). The volume of the penetration hole at $D_p/T < 5$ is, in all cases, larger than projectile volume, and at $D_p/T < 1$ it exceeds projectile volume by more than a factor of 10. Ideally, any bumper should generate (substantially) less displaced mass than that represented by the incoming projectile, as it otherwise exacerbates the orbital debris problem.

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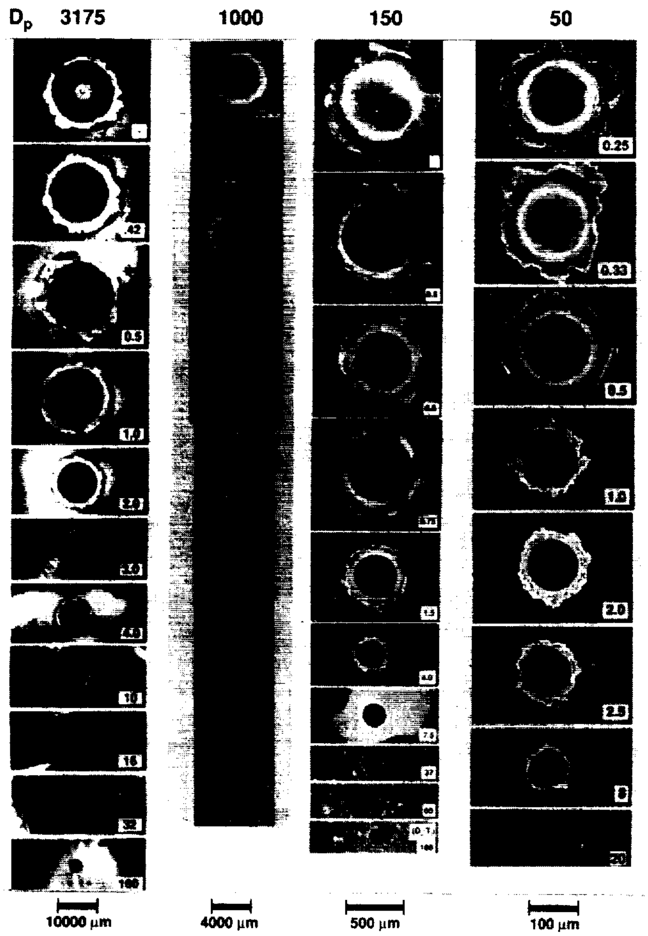

Figure 1. Relative size and morphology of craters and penetration holes produced by soda-lime glass spheres of 1/8 in. (3175 µm), 1 mm (1000 µm), 150 µm, and 50 µm in diameter (vertical columns) encountering, at 6 km/s, successively thinner aluminum targets of scaled thickness D_p/T (= number in lower right-hand corner of each image). Note the morphologic similarity of these penetration holes at any given D_p/T, regardless of absolute scale, and that hole diameter decreases systematically with decreasing target thickness.

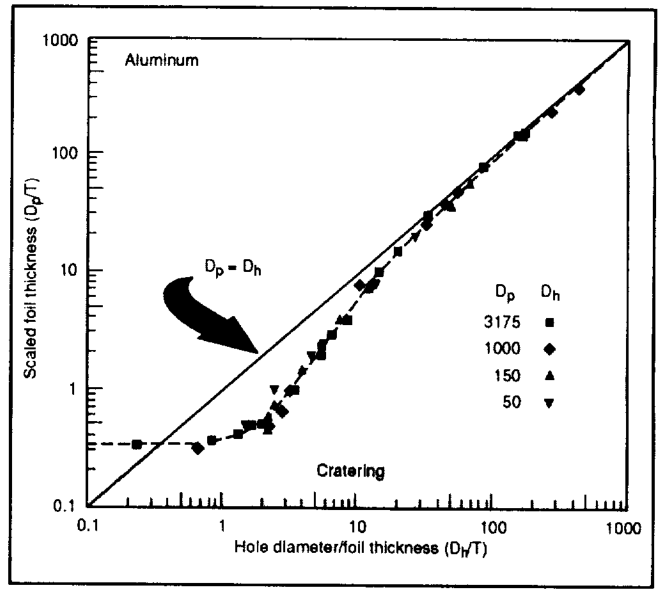

Figure 2. Measurements of penetration hole diameter (D_h), normalized to absolute foil thickness (T) versus the associated projectile diameter (D_p), also expressed in relative terms related to T. Note that all four projectile sizes combine into a single curve, attesting to the validity of the dimensional scaling approach.

Debris Concerns in Geosynchronous Orbit: Perturbations and Stable Planes

PI: **Donald J. Kessler, Ph.D./SN3**
Herbert A. Zook/SN3
Larry J. Friesen, Ph.D./LESC
Reference: **SSS 4**

Orbital evolution modeling for the geosynchronous Earth orbit (GEO) region has been under way as part of the effort to characterize the potential man-made debris collision hazard in Earth orbit. The purpose of the modeling is to determine if a wandering satellite or a piece of debris in a given initial orbit will remain in, or evolve into, an orbit that could endanger working GEO satellites. The model uses a very accurate numerical integrator and accounts for the gravitational force of the Earth, including nonspherical terms in Earth gravity, lunar and solar gravity, and solar radiation pressure. The most recent addition to the force model is atmospheric drag for transfer stage orbits.

Objects have been modeled starting in geosynchronous orbit and in possible "disposal orbits" a few hundred kilometers above and below GEO. These are assumed to be satellites at the ends of their operational lifetimes—with no propulsion and extremely sensitive to the perturbing forces. We have recently begun modeling transfer stage orbits, with perigees at low altitudes and apogees at GEO.

Objects initially in circular, equatorial, GEO, and near-GEO orbits were found to stay within about 50 km above or below the initial orbit radius. However, the combined influence of lunar and solar gravity, plus the Earth equatorial bulge, causes the orbital angular momentum vector for GEO and near-GEO orbits to precess about an axis inclined approximately 7.3° to Earth's North Pole (fig. 1). The resulting orbit plane precession causes the inclinations of initially equatorial orbits to increase to roughly 15°, then return to zero, in a 53-year repeating cycle. This result confirms previous studies using semi-analytical methods, and it means that wandering satellites can intersect the geosynchronous equatorial orbit at high relative velocities.

However, the result also suggests that a GEO orbit with an angular momentum vector aligned with the 7.3° inclined precession axis might be stable; that is, its orbit plane would not change with time. We conducted simulations for objects in such a GEO orbit, with initial inclination of 7.3° and initial right ascension of the ascending node of 0.0° (directly toward the vernal equinox).

The plane of this orbit is more stable, but not completely fixed. Over a period of decades, the inclination will change, but the orbit will never be more than 1.2° from its original plane. In addition, all objects in this orbit change their planes in the same way, so that if one places new satellites into this slowly changing "stable plane," relative inclinations can be maintained within 0.14°, and maybe less. Further, no stationkeeping maneuvers are required to maintain this.

The advantage of such an orbit is a reduction in encounter velocity between colliding satellites. GEO objects in initially equatorial orbits, with relative inclinations up to 15°, have maximum encounter velocities up to 800 m/s—artillery shell speed. In contrast, with careful placement of satellites into a "stable plane" orbit, encounter velocities can be limited to fewer than 8 m/s with respect to other objects in that stable plane. Such velocity reductions mean that fewer large debris fragments will be generated if a collision occurs, reducing, if not eliminating, the likelihood of a "collisional cascade," where those fragments cause still more collisions.

The price is that the satellite no longer occupies a fixed point in the sky as seen from Earth. A satellite in a "stable plane" orbit will undergo a daily north-south excursion and a smaller east-west excursion. Some satellite operators have already stated that the reduced on-orbit stationkeeping fuel cost is worth the higher ground operational cost. As technology lowers the cost of ground operations, this trade-off might make operations in the stable plane even more economically attractive.

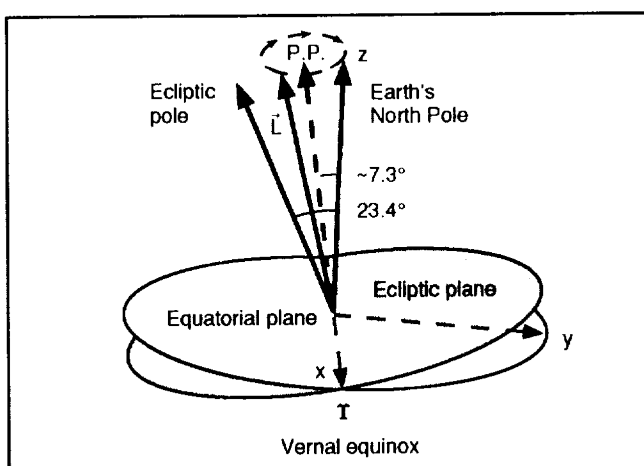

Figure 1. Orbit plane precession schematic for a large near-GEO satellite initially in an equatorial orbit. L is the satellite instantaneous angular momentum vector, which precesses about P.P., the "precession pole," in approximately 53 years.

Pneumatic Conveying of Solids in Partial Gravity

PI: **Thomas A. Sullivan, Ph.D./SN14**
Reference: **SSS 5**

The goal of this project was to evaluate the feasibility of pneumatic conveying for movement of regolith at a lunar base. Operation of a pneumatic transfer system at reduced (lunar and Mars) gravity on NASA KC-135 aircraft allowed the determination of some key parameters necessary for the design of an operable system. Both horizontal and vertical transfer were studied.

As plans are being made for the establishment of a permanent lunar outpost, the concept of lunar resource utilization gives a new meaning to the phrase "living off the land." Lunar soil may be used to produce oxygen, water, and radiation shielding, which astronauts will need to survive on the Moon. Lunar soil also may be used as a source of propellants and metals, resulting in enormous savings in transportation costs. These operations will require the mining and transport of lunar regolith.

Pneumatic conveying systems have proven successful on Earth for the transport of a variety of bulk solids, but behavior of these systems at partial gravity has not been explored. The objectives of this study were to observe the behavior of a pneumatic conveying system at partial gravity (g), determine its key parameters of operation, and compare the results to one-g behavior and theoretical analysis.

In vertical transport, the choking velocity is the critical point at which the air can no longer keep the solids aloft in the airstream. Collapse of the flowing solids to a slugging bed behavior is observed. Beyond this point, the flow transitions to dense phase vertical transport (an airlift) where slugging of solids up the pipe can occur. Predictive equations for dense phase vertical behavior are not readily available. The purpose of the vertical experiments was to measure this choking velocity for 150 μ glass beads (a surrogate for lunar soil) at the 3g levels. We also extended the measurements into the dense phase regime and measured the pressure drop as well as flow requirements beyond the choking point. A range of airflows was used in these experiments.

The purpose of the horizontal test was to determine the saltation velocity of the same 150 μ glass beads. Similar to the choking velocity, this is the critical point at which the air can no longer keep the solids aloft in the pipe. Below this velocity, the beads fall out of the airstream, forming a layer that rolls along the bottom of the pipe and can form dunes.

Theoretical analysis of factors that govern choking and saltation velocities predict a $\sqrt{g}$ relationship. The design of the experiment was complicated by the fact that the system was to be used for tests at 1.0g, 0.38g, and 0.16g. The airflows and air pressures predicted by these analyses spanned a broad range. Several constraints combined to make the final design a compromise. The final configuration was found to be workable at all g-levels in the vertical transfer mode. In the horizontal test, different factors perturbed the operation of the equipment in different ways at different g-levels.

Pressures, flows, and temperature were monitored for both experiments. The solids feed rate was set by use of a feeder, which was independently calibrated. Behavior of the solids in the pipe also was recorded on videotape for potential analysis by videometric techniques.

Actual measurements agree with predictions very well for the case of choking in a vertical pipe at lunar gravity. The choking velocities at lunar gravity are one half to one third of the velocity required at one g. Only one successful vertical run at Mars gravity was accomplished, and it differed from the predicted value slightly. Pressure drops across the pipe during dense phase transport also responded to partial gravity. The pressure requirement for lunar gravity is lower than for the one-g baseline.

Although experimental difficulties existed for the horizontal experiments, these runs, too, demonstrated that the saltation velocity and pressure drop at partial gravity are lower than those required on Earth. This should result in lower power requirements and lower pipe erosion than terrestrial systems.

Importantly, pneumatic conveying is a simple, reliable technology with few moving parts. Lower maintenance than a space-qualified dump truck therefore might be expected. It would not need onboard navigation or mobile power and thermal control systems. Smooth transitions from other functions, such as size classification or fluid bed processing, are likely. Even a rupture would result in only a few pounds of gas being lost, and this might be made up with indigenously produced gas.

It is hoped that the information gathered from this pilot study will be useful in the design and construction of lunar systems. By knowing the gas pressure and flow rate requirements, designs for pneumatic conveying systems on the Moon can be based on facts and factors such as compressor power, pipe diameters, and pressure variations that can be predicted. This can be followed by trade studies comparing pneumatic conveying with other alternatives for the transport of regolith.

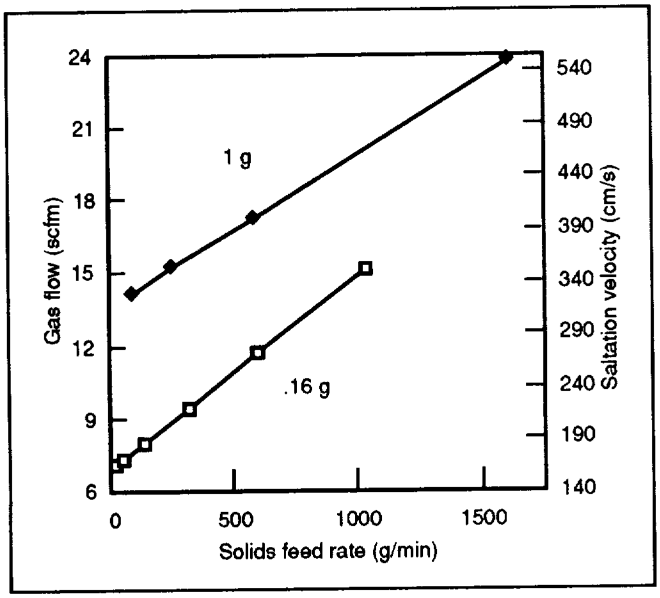

Figure 1. Theoretical saltation velocities versus g-level.

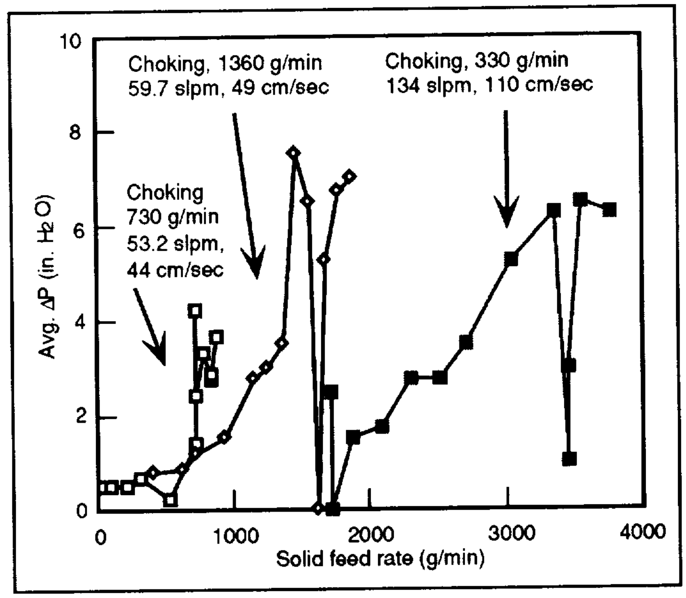

Figure 3. ΔP versus solid feed rate in the vertical conveying mode at 0.16g.

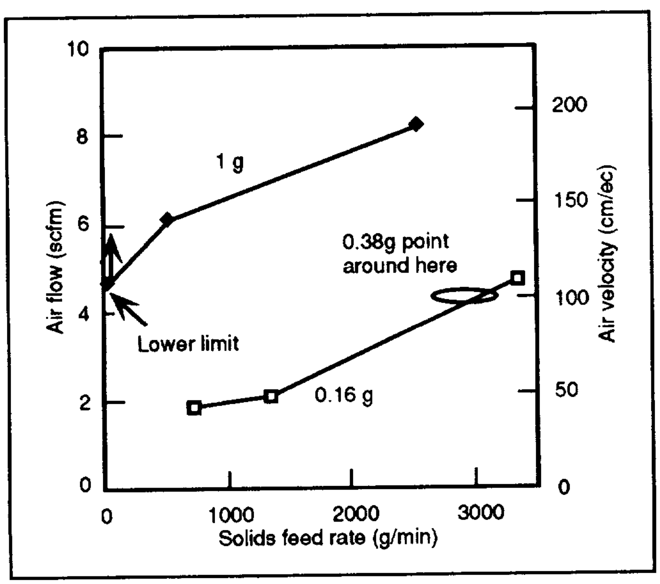

Figure 2. Observed chocking velocities versus solids feed rate.

Figure 4. Pneumatic conveying experiment performing at 1/6g on NASA's KC-135.

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Space Radiation Measurement, Analysis, and Predictions

PI: **Gautam D. Badhwar, Ph.D./SN3**
Michael J. Golightly/SN3
Alva C. Hardy/SN3
James E. Keith, Ph.D./SN3
Andrei Konradi, Ph.D./SN3
Reference: **SSS 6**

Space radiation is an important limiting factor in manned spaceflights. For the design of Space Station Freedom, NASA has adopted NCRP (National Council of Radiation Protection) recommended dose limits. The career limits are set to assure a no-greater-than 3% increase in probability of death from space radiation-induced cancer and depend both on the age and gender of the astronauts. A combination of flight duration and altitude used by the Space Shuttle assures that radiation exposure always stays well below the permissible dose limits. To ensure that the exposure is properly recorded, every mission carries on board six sets of passive thermoluminescent detectors (TLDs), distributed at various places within the crew compartment, as well as personal dosimeters for each crewmember. Even though the orbital parameters of Space Station Freedom closely resemble those of the majority of Shuttle missions, the proposed mission durations for individual astronauts will exceed the duration of any single Shuttle mission, and the projected dose received by individual crewmembers could fall within striking distance of the permissible radiation exposure limits.

Given these requirements, it is very important to maintain a good understanding of the radiation environment, to check the validity of current 20-year-old radiation models, to verify shielding codes used for predictive calculations, and to measure the linear energy transfer (LET) distribution of the radiation within the crew compartment. The LET is used to calculate the dose equivalent, which represents the radiobiological effectiveness of the radiation.

To achieve these goals, we have carried out a number of experiments using passive and active measurement techniques. We have determined the neutron spectrum from thermal energies to be about 10 MeV and measured the radiation dose distribution in a phantom head within the crew compartment of the Space Shuttle. We have flown a tissue equivalent proportional counter (TEPC) as well as an Air Force radiation measuring instrument on a number of Shuttle missions covering all extremes of operational Shuttle orbits during several years of the solar maximum. On two missions thus far, we have flown a proton and heavy ion detector telescope (PHIDE) capable of measuring the flux of the incident radiation, its energy distribution, and its ionic composition from H to Fe.

An important theoretical analysis has been performed to improve currently existing models of the galactic cosmic ray (GCR) environment by incorporating all available experimental data and producing a semi-phenomenological diffusion model of cosmic ray propagation to cover all phases of the 22-year solar cycle, which incorporates the magnetic polarity reversal on the Sun. The results indicate that the derived diffusion coefficient can be used to predict the intensity of cosmic rays in the heliosphere during repeated 22-year solar cycles and that the uncertainty in the predicted local cosmic ray spectrum has been reduced to 16%.

Figure 1 shows dose measurements for 28.5° inclination circular orbits as a function of altitude accumulated for all Shuttle flights on which passive TLDs were carried on board. The two lines bordering the experimental points are model predictions for periods of solar maximum and solar minimum activity. It should be noted that, as a rule, the model overpredicts the dose during solar minimum and underpredicts it during solar maximum. Clearly, a refinement of the model is needed.

The neutron spectrum inside the crew compartment during three Shuttle flights was deduced from measurements involving Bonner spheres and activated metal foils. The source of neutrons is the atmospheric albedo and secondary production by GCRs and trapped inner-belt protons. The energy spectra can be represented in the form $J(E) = AE - g$ where $g = 0.765;0.035$ and $A = (1.24;0.04) \times 10^4$ for STS-28, $(0.85;0.04) \times 10^4$ for STS-36, and $(6.50;0.27) \times 10^4$ for STS-31.

A phantom head was flown on STS-31 and was mounted with the right cheek against the right bulkhead in the crew cabin. The highest dose was measured adjacent to the bulkhead, tapering off across to the other side of the spacecraft. The results of these measurements and further analysis indicate that, even though the internal inner belt spectrum is known to peak in the 80 to 100 MeV range, no hot spots owing to the Bragg peak are produced at the center of the head.

Figure 2 shows a typical LET distribution within the Spacelab carried by STS-40. The GCR contribution has been subtracted from the experimentally obtained distribution, and the result is compared to model calculations using the AP-8 trapped radiation model. The observed intensities exceed the calculated values above an LET of 5.3 keV/mm, while for lower LET the situation is reversed. The probable cause of this discrepancy is the assumed proton energy spectrum, which, for low orbits, changes very rapidly with altitude.

Figure 3 shows six sets of GCR He fluxes measured during different phases of the solar cycle and the theoretical fits to the data, as well as the deduced unmodulated GCR proton flux outside the heliosphere.

Current work continues with monitoring of the radiation belt fluxes, using the TEPC as well as the PHIDE telescopes flown on the Space Shuttle. This work will be pursued in the future and will involve the Soviet space station MIR.

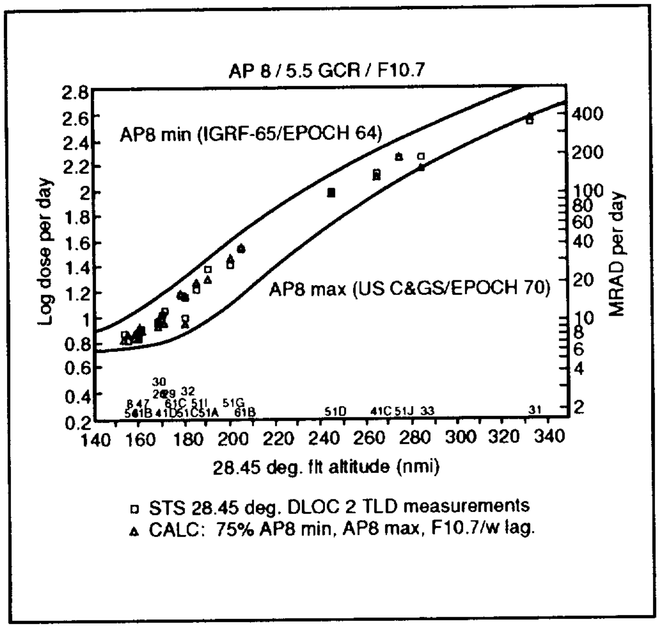

Figure 1. STS DLOC 2 measurement comparison.

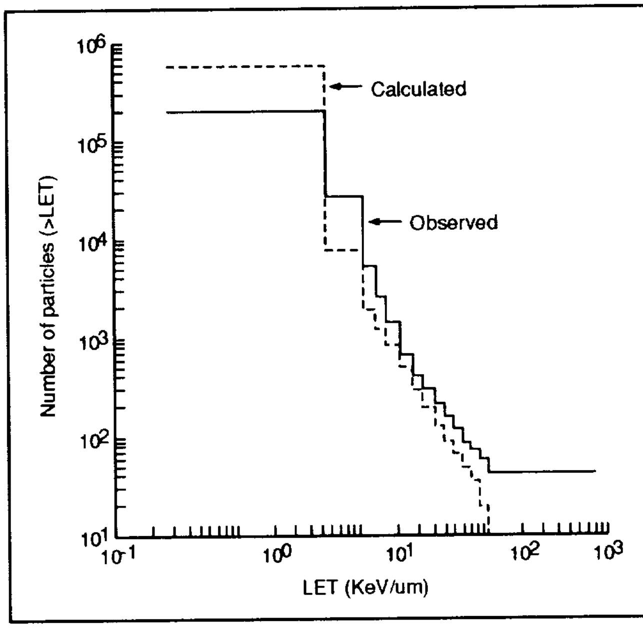

Figure 2. Typical LET distribution within the Spacelab carried by STS-40.

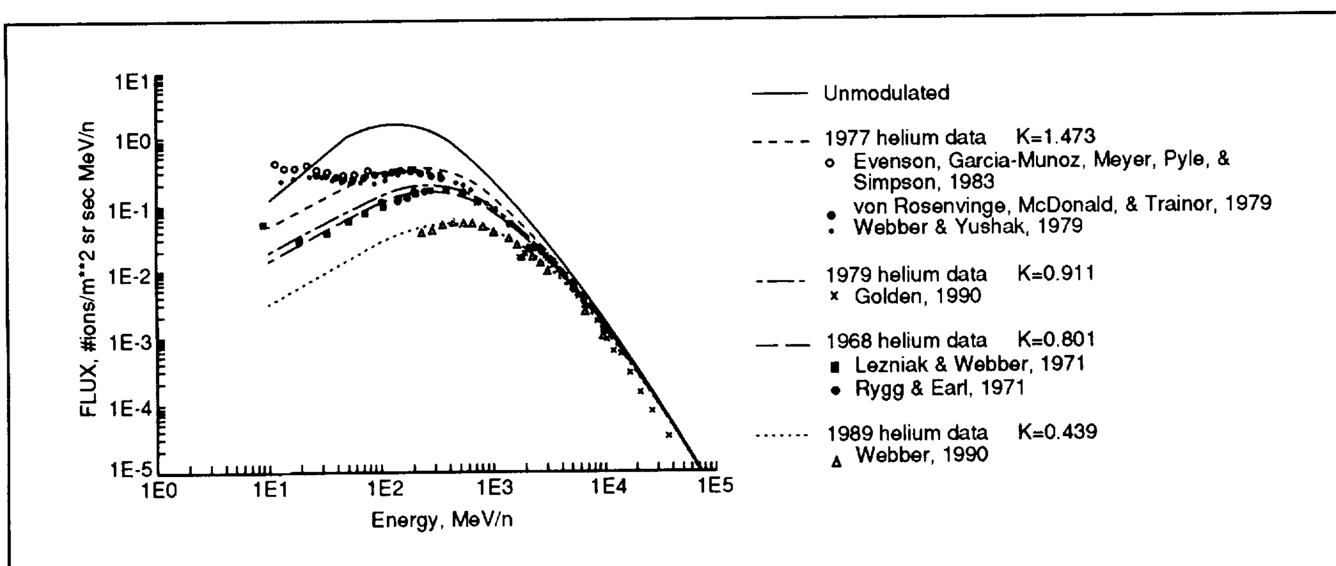

Figure 3. GCR He fluxes.

Space Systems Technology

Summary

Space Systems Technology

The research and technology thrusts pursued by NASA/Johnson Space Center (JSC) under Space Systems Technology represent current efforts that are focused on NASA long-range strategic goals and objectives associated with existing and planned programs and the new technologies they require. These efforts support Space Shuttle enhancements and evolution, Space Station Freedom initial capability and evolution, Earth orbit operations, advanced space vehicles, and space exploration with lunar, Mars, and interplanetary missions. Substantial progress has been demonstrated in these areas during the past year.

The Atomic Oxygen Effects experiment has as its co-investigators JSC, Ames Research Center, Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory, Langley Research Center, Lewis Research Center, and Marshall Space Flight Center, as well as Aerospace Corporation, the Air Force Geophysics Laboratory of Canada, the European Space Agency, and Japan. Accomplishments this year include completion of flight certification tests, the Space Shuttle Phase III Safety Review, and the assembly and functional checkout of the flight hardware. The Investigations of Spacecraft Glow experiment is scheduled for flight as an element of the OAET-1 payload on STS-61 during December 1993. This experiment design is being developed by Lockheed-Palo Alto Research Laboratory to study and characterize glow emissions in the ultraviolet, visible, and infrared wave-length ranges, and to determine how these emissions vary with orbital altitude and spacecraft surface temperature. The experiment critical design review was completed this year at JSC, and the Space Shuttle Payload Integration Plan was also baselined. After flight certification at JSC, the experiment package will be ready for OAET-1 integration by GSFC during early 1993.

In another effort, the use of lunar soil for the production of construction bricks was investigated. A heat transfer model was used to investigate the proposed sintering process. Results of this model were applied to the simulated lunar soil, MLS-1, to determine the effects of sintering parameters upon brick properties. Future experiment will focus on "hot-pressing" as an alternative to the sintering method.

Several experiments were conducted in the variable pressure growth chamber to demonstrate the use of higher plants grown in a closed, controlled environment as a component of an integrated Regenerative Life Support System. The tests resulted in scientific and engineering data characterizing crop growth and test-bed performance over the full cycle of a lettuce crop in a commercially available solid substrate. Other investigations in this area include Fundamental Process Enhancements in Electrochemical CO_2 Removal and Silver Oxide CO_2 Removal. These investigations have been very successful and have resulted in prototype full-scale model parameters being calculated. Further development in these areas continues for a totally integrated regenerative life support system design.

Several investigations in the area of failure tolerance were conducted in FY91. The two tasks reported in this section are the Manipulator Design for Space Operations and the Manipulator Joint and Controller Development. The significance of these efforts is to demonstrate that standard, scalable, modular failure-tolerant manipulator joint configurations would readily allow implementation of extra redundant degrees-of-freedom manipulator systems. This work includes the development of a sophisticated decision-making package to improve fault tolerance capability of the mechanism, as well as the test-bed architecture involving differential-before-gearbox configuration.

In the area of communications, tracking, and remote vision, JSC efforts include a Laser Orientation Transceiver System, a Wireless Infrared Data Acquisition System, Image-Based Tracking System, Optical Communication Through the Shuttle Window, Laboratory Demonstration of Innovative, Compact, 3-Dimensional Imaging Sensor, Exponential Grids in Robotic Vision, Hierarchical 3-Dimensional and Doppler Imaging Laser Radar, and Optical Correlations. These projects have progressed significantly in the past year.

During 1991, the autonomous navigation and guidance investigation focused on making improvements to the powered flight portion of the Shuttle return to launch site abort mode. A modification of the powered flight guidance was developed, and laboratory tests were conducted. This investigation did not achieve the desired improvement, but an approach to conducting another experiment was identified and will be investigated. Under control technologies, JSC developed the Space Station computational control workstation, an integrated hardware/software system for guidance, navigation, and control analysis.

The Space Station Heat Pipe Advanced Radiator Element II is aimed at developing high-capacity heat pipe radiator systems. A flight experiment was conducted on STS-43 to test monogroove heat pipe and graded groove heat pipe designs. Very useful data were obtained with revolutionary design information for future design for heat rejection/radiator systems. Another investigation focused on the Long-term Stability in Metal Hydrides due to rapid cycling and thermal aging. In this investigation, a new form of cyclic degradation was observed that is peculiar to vanadium-based hydrides. The exact cause of this is currently under investigation.

The software technology efforts at JSC continue to develop intelligent systems to assist humans in the real-time monitoring and fault management of complex space systems. Several tools, methods, and guidelines have resulted in FY91 and are reported in the project Making Intelligent Systems Team Players: Design for Human Interaction. These implementations incorporate knowledge capture and expert systems. Significant spinoffs in the private sector are anticipated as a result of these NASA software innovations.

Section IV

Space Systems Technology

Signficant Tasks

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EOIM-3 Atomic Oxygen Effects Experiment

PI: **James T. Visentine/ES**
Steven L. Koontz, Ph.D./ES
Reference: **SST 1**

The EOIM-3 (Evaluation of Oxygen Interaction with Materials-3) flight experiment, now under way by the Structures and Mechanics Division and the New Initiatives Office, has as its co-investigators Ames Research Center, Goddard Space Flight Center, Jet Propulsion Laboratory, Langley Research Center, Lewis Research Center, and Marshall Space Flight Center, as well as Aerospace Corporation, the Air Force Geophysics Laboratory, Canada, the European Space Agency, and Japan. The EOIM-3 is manifested on STS-46, with a tentative flight date of July 1992. It consists of active sensors and passive exposure trays installed on a payload support structure within the Orbiter cargo bay. The active sensors will be used to study atomic oxygen interaction mechanisms that lead to the unwanted changes in material properties and will enable accurate reaction rate measurements to be made for materials and surface coatings provided by the participating laboratories. The passive trays, which allow many more materials to be evaluated, will contain approximately 1100 thin-film disk specimens that will be analyzed after the flight is completed.

To implement the experiment objectives, an ion-neutral quadrupole mass spectrometer will be used to measure the ambient oxygen density during the exposure period and identify reaction products generated by neutral atom interactions with material surfaces. Controlled exposure will be accomplished by flying the Orbiter with its payload bay into the velocity vector for 40 hours at a reduced altitude of 130 n. mi. During the exposure period, the mass spectrometer will be rotated first to view along the orbital velocity vector analog output to obtain atomic oxygen (AO) neutral density measurments, and then toward a rotatable carousel, which will alternately expose material samples to the mass spectrometer for analysis. Materials used within the carousel sectors will be isotopically labeled prior to flight to distinguish the atomic oxygen reaction products from common background gases generated within the Shuttle cargo bay.

Additional sensors and heated exposure trays will be used to study the effects of temperature, mechanical stress, and solar radiation on reaction rates. A sensor that exposes samples first to daylight and then to nightside orbital passes will be used to determine whether solar energy accelerates the molecular interaction process. Scatterometers will also be provided by the participating laboratories to estimate AO energy accommodation on surfaces and define atom-surface emission characteristics as related to surface recession.

Accomplishments this year include completion of flight certification tests, the Space Shuttle Phase III Safety Review, and assembly and functional checkout of the flight hardware. Selection of the final sample set for the experiment was completed and coordinated with the other investigators at the EOIM-III working group meeting in late August 1991. The NASA/ Johnson Space Center (JSC) sample set is designed to combine synergistically basic science investigations of atomic oxygen chemistry with Space Station Freedom program support. The sample set includes candidate elastomers for docking bumpers and hatch seals, tribomaterials, and thermal control and electrical insulation materials. Several important materials issues were uncovered during sample preparation and are being followed up by the Work Package-2 prime contractor. Specifically, cracking of Z-93 space paint during low-temperature vacuum baking and poor outgassing performance of some elastomers are potential program problems. In addition, AT&T Bell Labs and the Chemistry Department at Rice University and Los Alamos National Laboratory have agreed to participate as coinvestigators with JSC in advanced materials studies. Diamond-thin films, new fluorocarbon lubricants, high-temperature superconductors, and semiconductor processing will be investigated as part of the EOIM-III experiment.

The final preflight calibration of the EOIM-III flight mass spectrometer was conducted at Los Alamos National Laboratory in mid-November 1991. The mass spectrometer had been cleaned and renovated by the Phillips Laboratory (owners of the instrument) prior to this calibration in an attempt to correct instrument contamination problems observed in earlier calibrations. Cleaning and rebuilding eliminated contamination problems successfully, even though the calibration has changed significantly. Calibration stability studies will continue as the payload integration schedule permits, and a postflight calibration check will be conducted in late 1992.

Ground support equipment development neared completion with the successful operation of the flight telemetry workstation. The flight telemetry workstation consists of two IBM 386 computers working in series on the data stream from the Payload Operations Control Center data port dedicated to EOIM-III and Temp 2-A3. The first IBM 386 handles telemetry decommutation and routes data to various EOIM/TEMP investigators. The second IBM 386 serves as the EOIM-III data display and analysis computer, permitting near real-time analysis of the mass spectrometer, atomic oxygen monitor, quartz crystal microbalance, and temperature data. The two computers share the same "scuzzy" disk drive to permit rapid transfer of data blocks without data traffic jams. The workstation system will support preflight integration and payload testing during experiment processing at the NASA/Kennedy Space Center.

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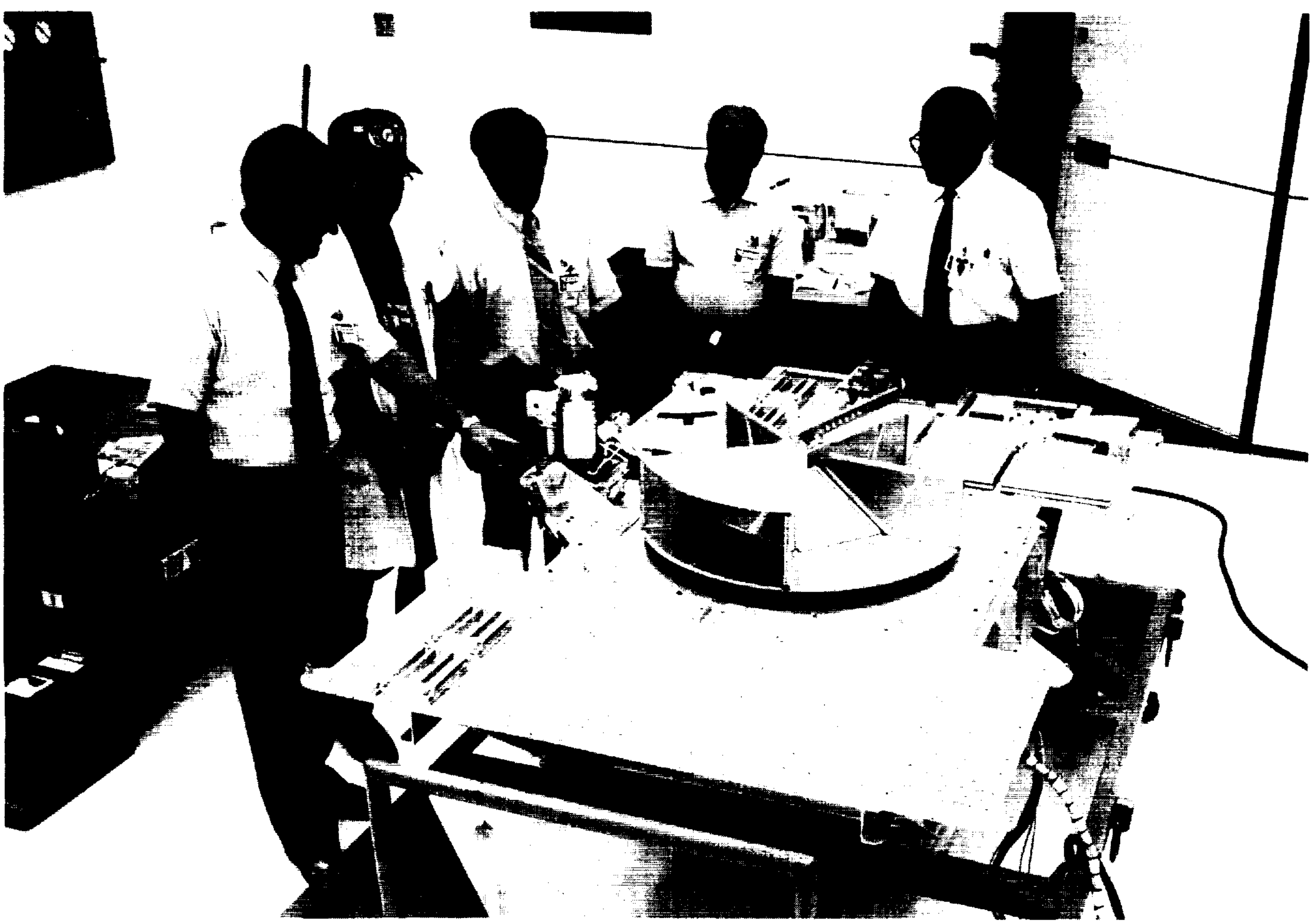


Figure 1. EOIM-3 and the JSC Flight Projects Team.

Experimental Investigations of Spacecraft Glow

PI: **James T. Visentine/ES**
Reference: **SST 2**

This experiment, which is scheduled for flight as an element of the Office of Aeronautics and Space Technology (OAST)-2 payload on STS-62 during January 1994, is being developed for NASA by the Lockheed-Palo Alto Research Laboratory to study and characterize glow emissions in the ultraviolet, visible, and infrared wavelength ranges, and to determine how these emissions vary with orbital altitude and spacecraft surface temperature. To accomplish these objectives, glows investigated by this experiment will be produced by (1) the natural atmosphere, (2) Orbiter thruster effluents passing above the ram, or normal incidence, side of a passive sample plate, and (3) molecular nitrogen released above this plate by an on-board pressured gas cylinder and flow control system.

The experiment will include a pallet-based set of sensors, two passive sample plates, and a nitrogen gas-release system for study and operation within the Orbiter cargo bay. Sensors developed for this experiment include (1) a visible imaging spectrometer, (2) a far-ultraviolet imaging spectrometer, and (3) two cryogenically cooled, Indium Antimide infrared (IR) detectors. During the mission, the IR detectors will be cooled to at least 84 K by a Joule-Thompson cryostat system, which operates using a non-contaminating (argon) pressurized fluid as the refrigerant gas. A dedicated experiment processor and avionics system will also be developed to control sensor operation for at least four orbits (two circular and two elliptical) of data-taking sequences.

During this year, a critical design review meeting and the Phase O/I safety review were completed at NASA/Johnson Space Center (JSC), and the Space Shuttle Payload Integration Plan was baselined. Hardware design remains on schedule and supports completion dates for the flight optics, camera systems, digital records, sample plates, and flight electronics during early 1992. The experiment will be available for OAST-2 integration by Goddard Space Flight Center during early 1993 after the flight certification tests are completed at JSC. The data base generated by these measurements should enable NASA, the Department of Defense, and other users to establish operational procedures and design guidelines that will reduce the undesired effects of glow emissions on sensitive scientific experiments conducted during future missions of the Space Shuttle and Space Station Freedom.

Production of Construction Bricks from Lunar Soil

PI: **David Altemir, Joy Hines/ES**
Reference: **SST 3**

The Nonmetallic Materials Section (ES53) is supporting the Mission Science and Technology Office (SN14) in studying sintering as a viable process for the manufacture of bricks from lunar soil. Applications for lunar bricks include the construction of road beds, landing pads, foundations, radiation shielding, and unpressurized structures for a lunar outpost. The possibility of using the spent material from an oxygen production facility as a feedstock for the sintered brick-making process is also being investigated. The primary purpose of this work is to determine whether a simulated lunar soil, MLS-1, can be sintered so the resultant strength is comparable to that of concrete.

A heat transfer model of a lunar brick created by the Structures and Mechanics Division Thermal Branch (ES3) was used to investigate the proposed sintering process. Results from this model were then used in experiments that used the MLS-1 simulant to determine the effects of sintering parameters upon brick properties (fig. 1). The compressive strength of sintered lunar soil is strongly dependent upon temperature, heating time, greenbody (pressed) formation pressure, chemical composition, and grain size. The dependence upon these parameters is being determined in the lab by sintering test samples under varying conditions. The conditions under which test specimens with the strength of concrete have been produced by sintering are shown in figures 1 and 2.

As indicated in figure 2, strengths in the range of concrete were realized for those samples pressed above 36,000 psi. Unfortunately, these pressures translate into exceedingly high press requirements and launch mass needed for the production of large (20 × 20 × 40 cm) bricks on the lunar surface. On the other hand, an oxygen production facility would eject spent regolith at the elevated temperatures necessary for a brick-making process, thus eliminating the need for additional heat to be added to the system.

Consequently, future experiments will focus on "hot-pressing" as an alternative sintering method in which the preheated material from an oxygen production facility is pressed in an insulated mold. Lower die pressures as well as lower temperatures are expected to produce bricks of sufficiently high strength using this process. Other research topics to be investigated in FY92 are inductive heating, microwave heating, the effects of soil glass content, and the measurement of MLS-1 thermophysical properties, all with a view to assembling a demonstration test-bed and common lunar lander experiment.

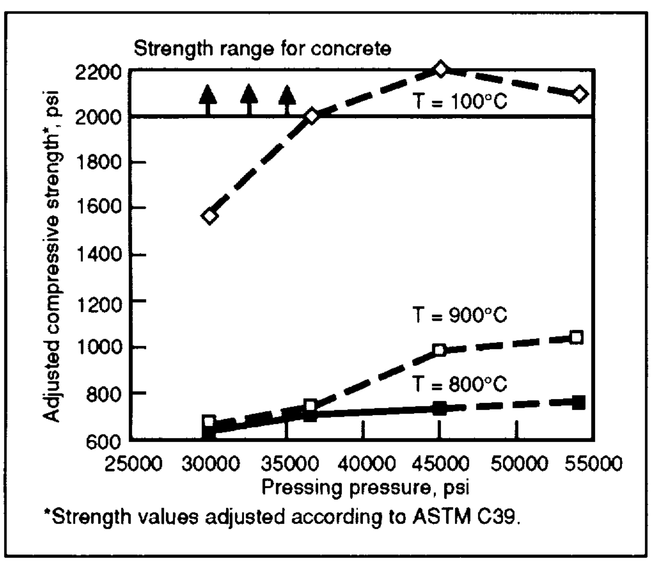


Figure 1. Sintered strength versus sintering temperature and pressing pressure.

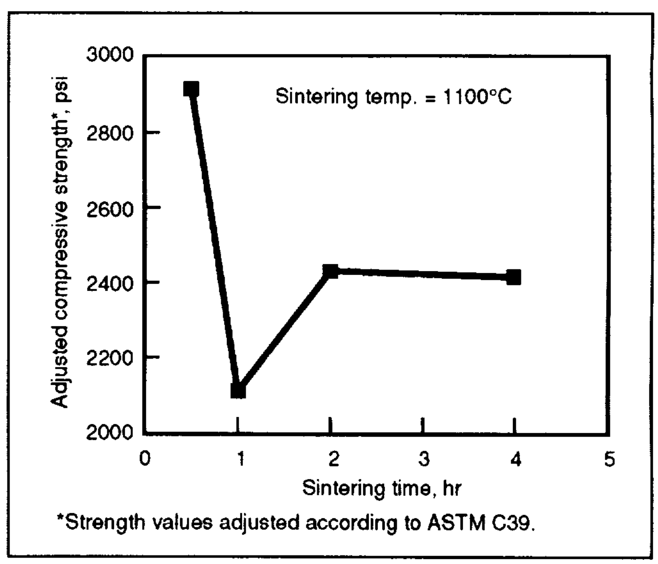


Figure 2. Sintered strength versus sintering time.

Regenerative Life Support Systems Test-Bed Crop Tests

PI:	**Donald L. Henninger/EC3**
	Terry O. Tri/EC3
	Daniel J. Barta/EC3
	Randal S. Stahl/EC3
	Marybeth A. Edeen/EC7
Reference:	**SST 4**

Following buildup and checkout of the variable pressure growth chamber (VPGC), four lettuce crop tests were conducted in the VPGC (fig. 1). These tests demonstrated the use of higher plants grown in a closed, controlled environment for use as a component of an integrated regenerative life support system.

The tests were performed to obtain scientific and engineering data characterizing crop growth and test-bed performance over the full cycle of a lettuce crop, from seed to harvest in a commercially available solid substrate. Test objectives included: (1) characterization of engineering system performance; (2) verification of the bioregenerative life support system potential of crop growth in a closed, controlled atmosphere; and (3) determination of CO_2 uptake, O_2 production, evapotranspiration, and biomass production as a function of crop maturity.

Unique characteristics of each crop test are listed below.

- VPGC Facility Verification Crop Growth Test

  Performance of the chamber engineering systems was verified.

- Lettuce Crop Characterization Test I

  The bioregenerative life support system potential of lettuce grown in a controlled environment was demonstrated. The chamber was entered four times prior to harvest to obtain intermediate growth data.

- Lettuce Crop Characterization Test II

  Crop growth in a closed system without entry was demonstrated. The crop was grown as a replicate of the first Lettuce Characterization Crop Test to provide a measure of the variability of crop performance over test cycles.

- VPGC Model Development and Verification Test

  Data were obtained to validate the VPGC model developed by McDonnell Douglas Space Systems Company using a Box-Behnken experimental design. CO_2 level, dewpoint temperature, airflow, and light level were systematically adjusted to determine the effect on condensate collection and CO_2 utilization.

Tests planned for FY92 include

VPGC:

- First Wheat Crop Characterization Test

Ambient Pressure growth Chamber:

- Facility Verification Crop Test
- Hydroponic Lettuce Crop Characterization Test

Figure 1. Internal view of the VPGC with mature lettuce crop.

Silver Oxide Carbon Dioxide Removal

PI: **Robert J. Cusick/EC3**
Reference: **SST 5**

Work began in March 1991 to develop a new configuration of metal oxide material to absorb carbon dioxide (CO_2) for life support metal oxide regenerative extravehicular activity system (MORES) application. Previous development of regenerable metal oxide material had been as pellets of 0.8 to 1.4 mm diameter size range. Cycle life has been limited to an attractive 50 cycles due to attendant agglomeration of pellets and the resulting increase in pressure drop of the processed breathing air. As illustrated, a new thin sheet form of the silver oxide (AG_2O) material formulation sandwiched between layers of screens and fins to form a matrix (0.097 in. thick) has been developed to extend the cycle life to 100 cycles and to extend performance cycle time from 3 hours to 8 hours. During extravehicular activity (EVA), space suit breathing air is passed through the canister and metabolic CO_2 reacts with the AG_2O to form silver carbonate (AG_2CO_3). Subsequent to the EVA, the canister is removed from the portable life support system and placed into a regeneration package. Cabin air is heated to 480°F and passed through the canister. The application of heat reverses the chemical reaction to regenerate the AG_2O by releasing CO_2 from the AG_2CO_3.

A sheet-matrix, stainless steel canister (fig. 1) with the same internal volume as the nonregenerable, aluminum Shuttle EVA lithium hydroxide (LiOH) contaminant control cartridge (CCC) has been initially tested with a load of the metal oxide sheets. Compared with the weight and external volume of the nonregenerable CCC, 6.4 lb and 0.175 ft^3 respectively, the MORES sheet-matrix canister weight and volume are 28.6 lb and 0.214 ft^3. The previous aluminum CCC metal oxide pellet canister weight and external volume were 13.7 lb and 0.175 ft^3. Large tolerances within the canister allowed the sheets to grow upon repeated cycling during this initial test in August 1991. Eventual restriction of airflow resulting in excessive pressure drop permitted only 50 cycles of testing with no loss in chemical CO_2 removal performance. A cycle consists of 8 hours of CO_2 absorption followed by 6 hours of regeneration. Design tolerances were tightened and the canister was reloaded in November 1991. After 70 cycles to date, CO_2 removal performance has decreased only 10% over the last 15 cycles. Pressure drop has increased approximately 12%. Further testing will be conducted at the Crew and Thermal Systems Division following hardware delivery in May 1992.

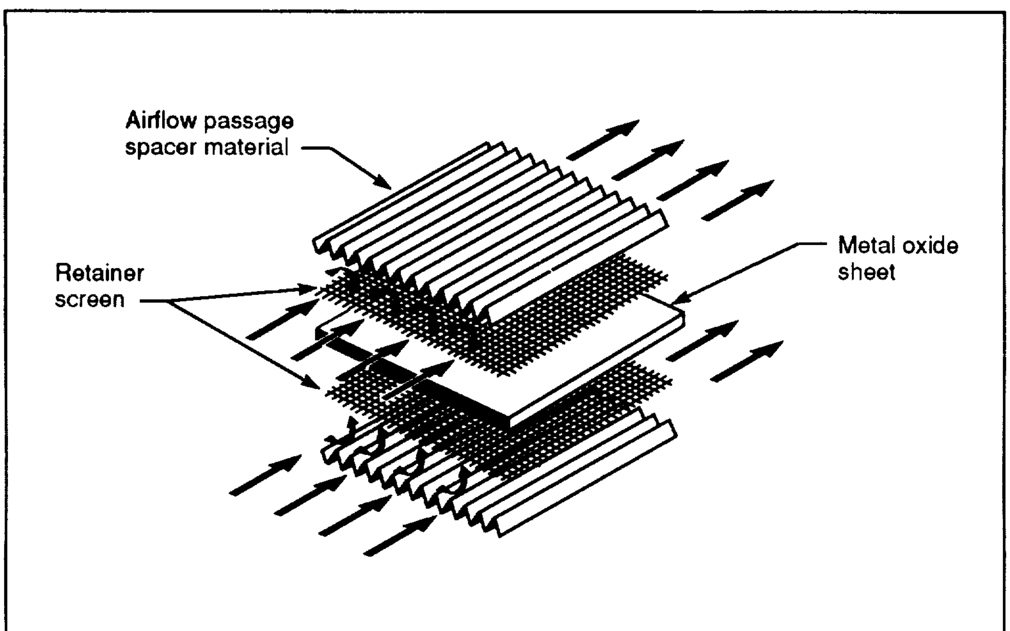


Figure 1. Sheet matrix reactor configuration.

Fundamental Process Enhancements in Electrochemical Carbon Dioxide Removal

PI: **Sandra L. Foerg/EC3**
Reference: **SST 6**

The objectives of this research and development program are to identify and develop improvements in electrochemical carbon dioxide (CO_2) removal technology. Processes both with and without the use of hydrogen (H_2) (fig. 1) are being investigated. In the presence or absence of H_2, the CO_2 reacts with hydroxyl (OH) ions at the cathode to form bicarbonate (HCO_3) ions and then carbonate ($CO_3^{=}$) ions. The diffusion and migration of CO_3^{-}, HCO_3, and OH^{-} ions and water molecules occur in the electrolyte matrix, a highly microporous, hydrophillic, and densely compressed material. At the anode, when H_2 is supplied, dissolved H_2 reacts at the electrode to form hydronium ions (H_3O^+), lowering the pH in the region to cause the evolution of CO_2 from $CO_3^{=}$. When H_2 is not supplied, H_3O^+ is formed from water, causing the evolution of CO_2 from $CO_3^{=}$.

The Phase I program, completed in February 1990, consisted of fundamental studies on electrochemical CO_2 removal processes through literature and laboratory testing, selection of electrochemical cell components, and performance testing at a single cell level for both processes with and without using hydrogen. In Phase II, a hybrid air revitalization concept was developed, which applies the without-hydrogen electrochemical CO_2 removal process in combination with an electrochemical oxygen separator and a physical moisture separator. A system of this design (fig. 2) could provide optimal environments for the space crew and the plant habitat for long-duration, advanced space missions. Subscale electrochemical carbon dioxide separator (ECSM) and electrochemical oxygen separator (EOSM) modules were built, and the test setups for proving the concepts were assembled and tested.

Accomplishments in FY91 include the characterization of the performances of the subscale ECSM and the EOSM, both separately and combined. Parametric testing showed that the ECSM cell voltage ranged from 1.05 V to 1.40 V as the cell current increased from 5 A to 10 A. The EOSM cell voltage for separating oxygen from either CO_2/oxygen (O_2) or nitrogen/O_2 mixture ranged from 0.96 V to 1.10 V as the cell current increased from 5 A to 10 A. Furthermore, the results from the combined testing of the ECSM and the EOSM indicated that CO_2 concentration of higher than 95% can be achieved at the EOSM outlet without causing high EOSM cell voltage. A 6-month extended effort in Phase II for additional parametric testing was initiated November 1991.

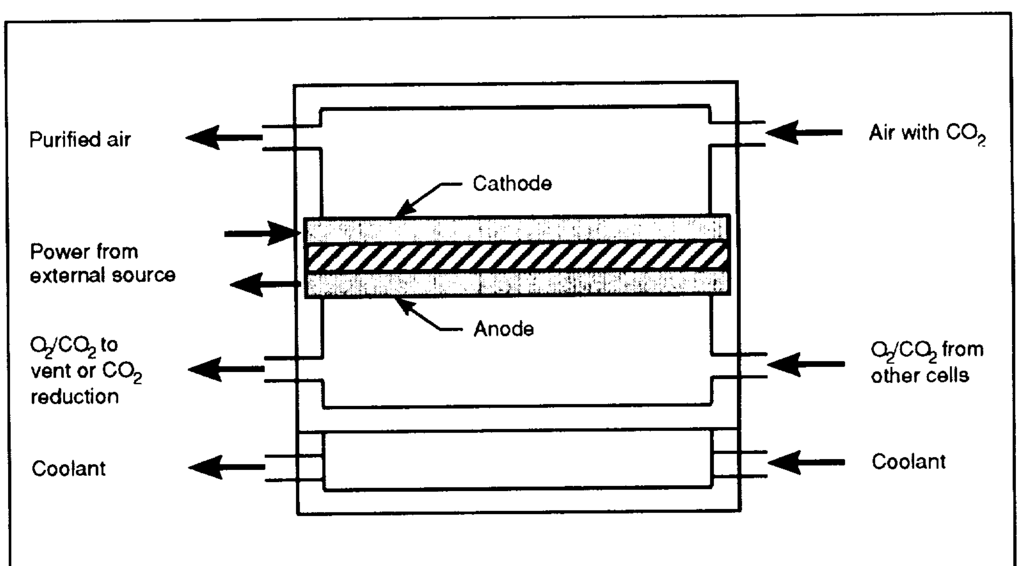


Figure 1. Electrochemical CO_2 removal without hydrogen.

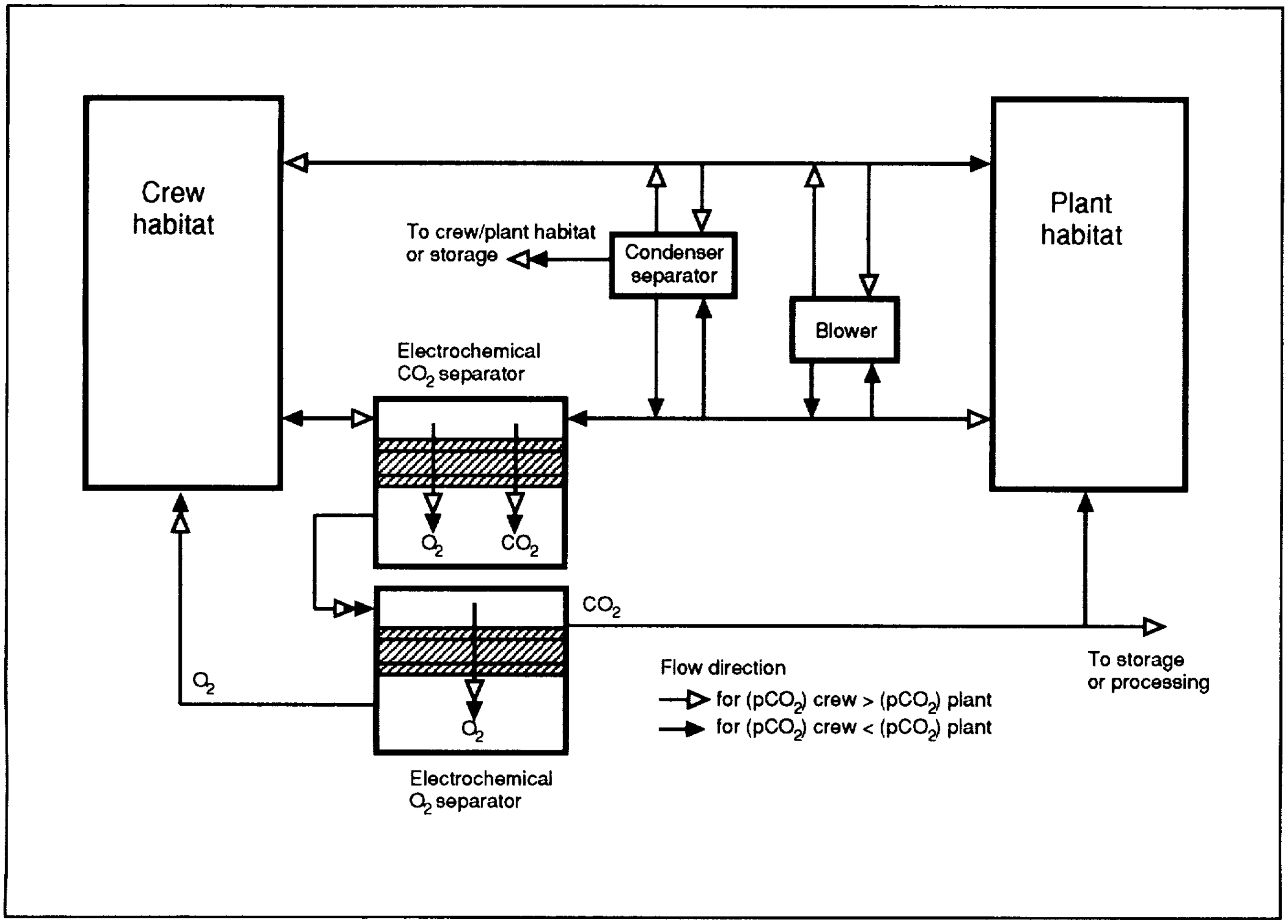


Figure 2. Hybrid air revitalization system concept block diagram.

Failure Tolerance in Manipulator Design for Space Operations

PI: John T. Chladek/ER43
Reference: SST 7

In FY90, a research grant was initiated for the University of Texas at Austin to create a program for developing fault-tolerant reconfigurable manipulator structures and adaptive control concepts. Space-based systems must employ failure tolerance for reasons of safety, mission success, and to minimize operational limitations and constraints.

The task is to address three new areas in robotics: (1) developing a fault-tolerant joint module that is compact and scalable in size; (2) implementing various sizes of these scalable modules into readily reconfigurable manipulator architectures tailored to the application; and (3) developing sophisticated decision-making system controls that would vastly improve the failure tolerance capability offered at the individual joint level. Control of such configurations will require continuing research into disturbance rejection from failure occurrences. Adaptive control techniques will require development with fault-tree selection and decision-tree procedures.

The approach is to provide structural redundancies, or alternative capabilities, at four levels of fault tolerance in a modular manipulator architecture. The first level is in the dual-actuator module (prime mover) with independent servo controllers, which becomes a common building element. Second-level fault tolerance is accomplished by parallel or redundant mechanism structures. The third level of fault tolerance uses criteria-based decision-making software in a fault-tree structure for controlling the first two levels of fault tolerance capabilities during disturbances (failures). The fourth level is accomplished by duality of the entire mechanism. This development will be implemented in a test-bed to evaluate fault tolerance in mechanical structures and will be composed of a 4-legged, 16-motor, 4-gimbal mechanism prototype (fig. 1). The mechanism will be capable of fault recovery both mechanically and electrically at several levels and will be able to demonstrate three levels of fault tolerance. FY90 accomplishments include the design and development of a fault-tolerant compact dual-actuator module. This compact dual-actuator module is scalable and forms the first-level basis for modular reconfigurable manipulator systems. FY91 accomplishments include the overall design of the test-bed along with the in-depth design and testing of a 2 degree-of-freedom (DOF) gimbal module. This gimbal module will be another common element in its use in the mechanism test-bed.

This work is significant in demonstrating that standard, scalable, modular failure-tolerant manipulator joint configurations would readily allow implementation of extra redundant DOF manipulator systems. In space-based manipulators, these extra joints would provide enhanced dexterity and usefulness in configuration variations and would provide tolerance to failures for long-duration use with extended maintenance requirements. Extensive future work will be required for control of these many DOF manipulator systems. A sophisticated decision-making package utilizing adaptive controller synthesis or linearized gain scheduling for reacting to internal disturbances (failures) is being developed and will be incorporated to dramatically improve the fault tolerance capability of the mechanisms.

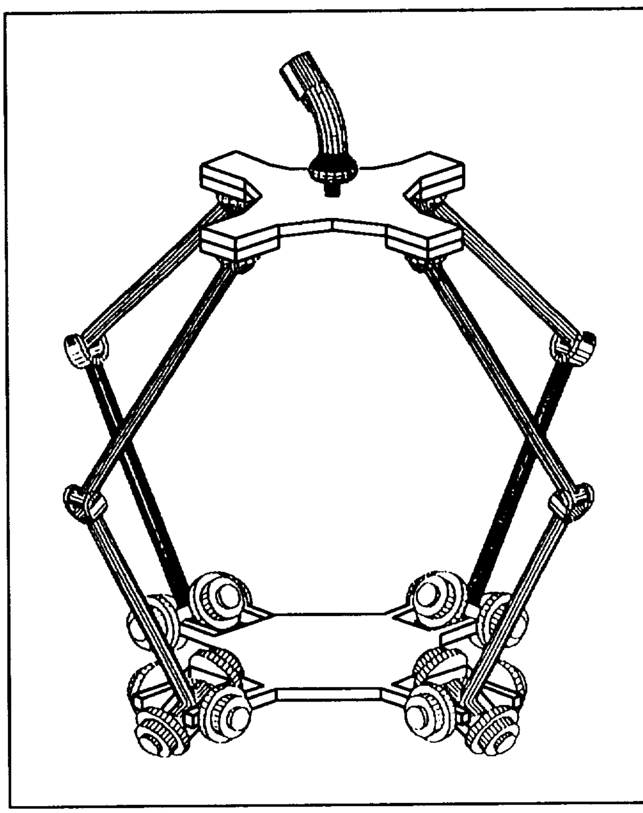


Figure 1. Conceptual 16-input, 3-level fault-tolerant workstation.

Failure-Tolerant Manipulator Joint and Controller Development

PI: **John T. Chladek/ER43**
Reference: **SST 8**

The design of the Shuttle remote manipulator system (SRMS) on the Orbiter is based on a chain of six serial mechanical joints controlled by a single string of electronics and electro-mechanical actuators. It is an adequate system, but due to the possibility of failures causing uncommanded motion, the SRMS is restricted in its allowed operations. In addition, if a joint electro-mechanical failure occurs, the coordinated control of the remote manipulator system end effector is lost.

A dual-actuator manipulator joint design was, therefore, investigated that could transparently absorb any drastic controls or electro-mechanical failure. This would eliminate current operational restrictions by minimizing uncommanded motion due to failures and task continuance.

The concept investigated incorporates two motor servo modules driving a dual-input differential drive mechanism that drives an output joint. This would allow one servo motor module electrical or mechanical failure and still continue the normal joint output operation without degradation. Engineering modeling and simulation proceeded, and a laboratory implementation was completed to verify the modeling and simulation results. FY90 efforts reviewed and analyzed differential drive concepts. Failure-transient effects were the main area of focus. Differential gear train dynamics were modeled, with torsional flex for the elastic mechanical components, to include the torsional resonance phenomenon. Several mechanical configurations were assessed and the effects of fault-transient response were studied. The FY91 effort completed the design and development of a mechanism hardware test-bed to allow comparison of operational transient responses to the analysis. The test-bed allows testing of various proposed mechanical configurations. Development of the controller systems continues. One architectural configuration was tested—dual servo modules driving gearboxes-before-the-differential—which then drove an output joint inertial load. Control concepts (figs. 1 and 2) were tested for transient stability during the induced failures. A paper was presented on this topic at the 1991 IEEE International Conference on Robotics and Automation.

Several significant benefits are provided by this concept over proposed space-based redundant drive manipulator joints. The concept mechanically removes the direct coupling between the redundant motor servo modules and allows continued operations of the joint by the differential drive characteristic after any of these single-failure modes, which stop operations of other proposed concepts. This differential drive concept is unaffected by any of these failure modes since it would de-energize the failed servo system and activate the fail-safe brake on that side. This concept also allows for both servo modules to participate in the joint drive and allows dynamic failures to be absorbed by the second servo system. A manipulator is thereby allowed to operate through a failure with minimum disturbance to the coordinated end-point control and to minimize uncommanded motion.

Future plans include reconfiguring the analysis and test-bed architecture from a dual-gearbox-before-the-differential configuration to a differential-before-gearbox configuration. Additional analysis will be attempted to determine the effects on dynamic stability during a failure-transient event as a function of load inertia.

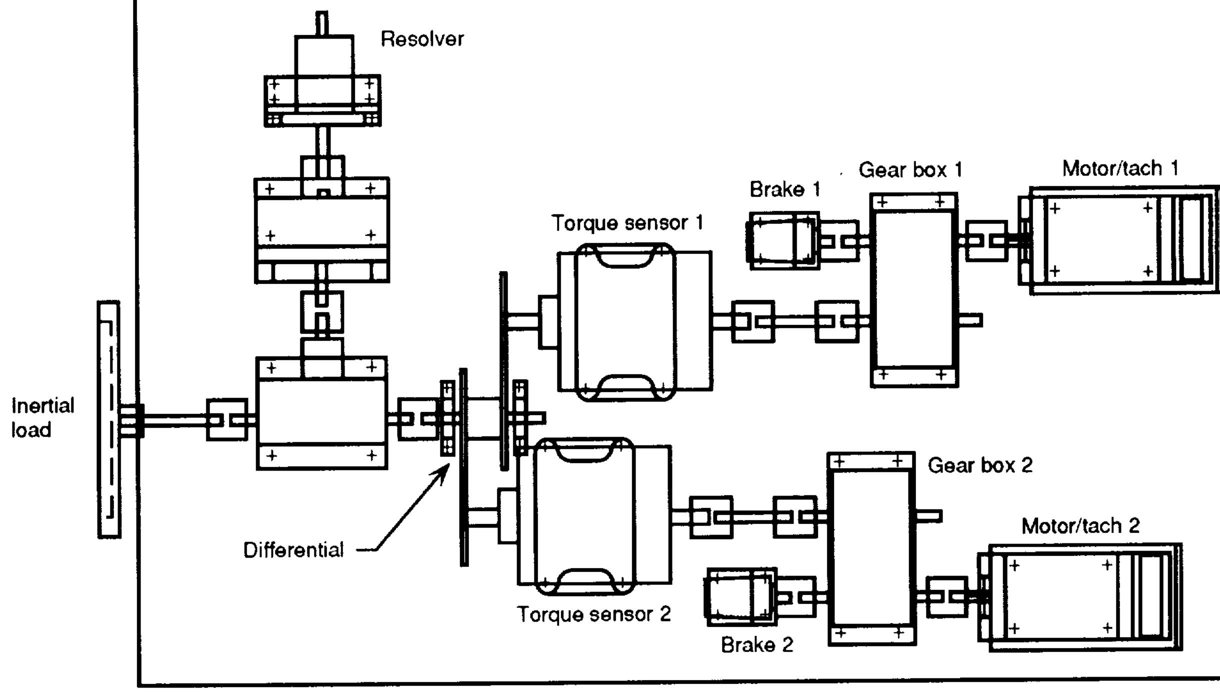
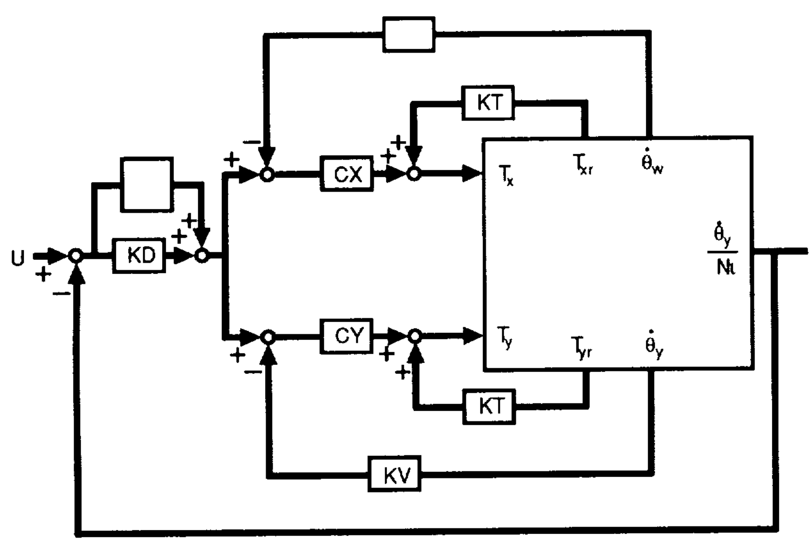


Figure 1. Failure-tolerant joint test assembly.



KD — System forward gain with joint output speed servoing.

KI — Integrator to eliminate steady-state error.

GX/GY — Equal or unequal load sharing between two actuators.

KV — Local tachometers feedback to enhance system damping.

KT — In-line torque sensing for feed-forward torque control.

Figure 2. Dual-driving differential system controller.

Laser Orientation Transceiver System

PI: J. L. Prather/EE
Reference: SST 9

This is a Small Business Innovative Research project for developing and demonstrating a capability to determine the relative orientation (pitch, yaw, and roll) of a target on which a single, unique retroreflector is mounted. This innovation has potential application to spacecraft rendezvous, stationkeeping, docking, berthing, remote manipulator grappling, satellite servicing, space proximity operations, air-to-air refueling, aircraft landing systems, and industrial and commercial alignment needs.

The technique makes use of the phenomenon in which the polarization of a laser beam is uniquely modified upon retroreflection by an amount dependent on the orientation and material properties of the retroreflector. Three-axis orientation is determined by using a different material on each facet of the retroreflector (such as gold, germanium, and molybdenum) and measuring the resulting polarization shift. This technique is relatively simple, with no inherent maximum or minimum range limitations and very small size and weight scarring of the target vehicle (fig. 1). Accuracies within 0.3° are predicted based on Phase I analyses and tests.

The Phase II three-axis prototype hardware was delivered in July 1991. Preliminary testing was performed, which indicated the system accuracy was approximately 0.5°. More exhaustive evaluations will be performed in FY92.

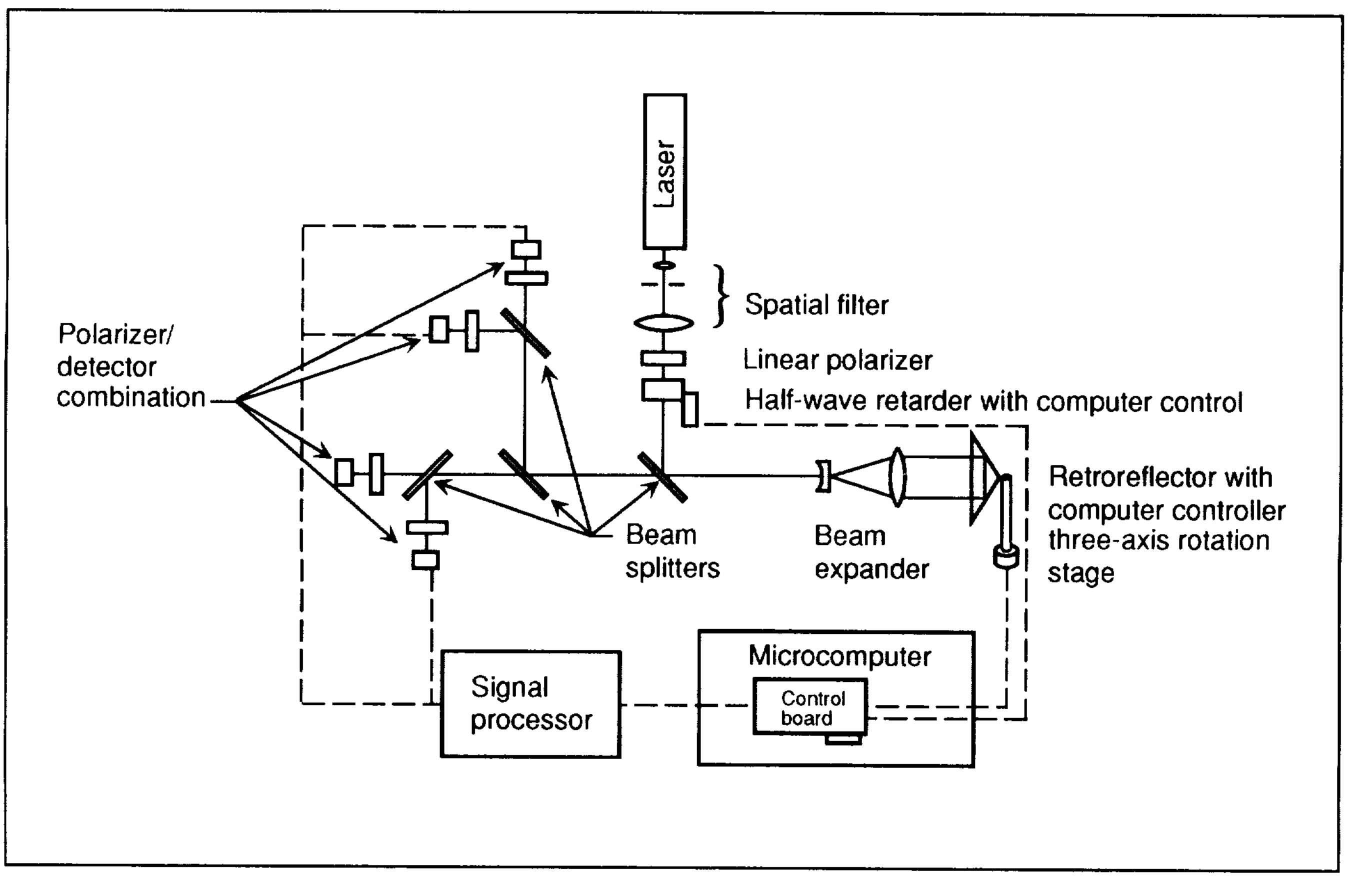


Figure 1. Schematic diagram of the transceiver system.

Wireless Infrared Data Acquisition System

PI: K. F. Dekome/EE6
Reference: SST 10

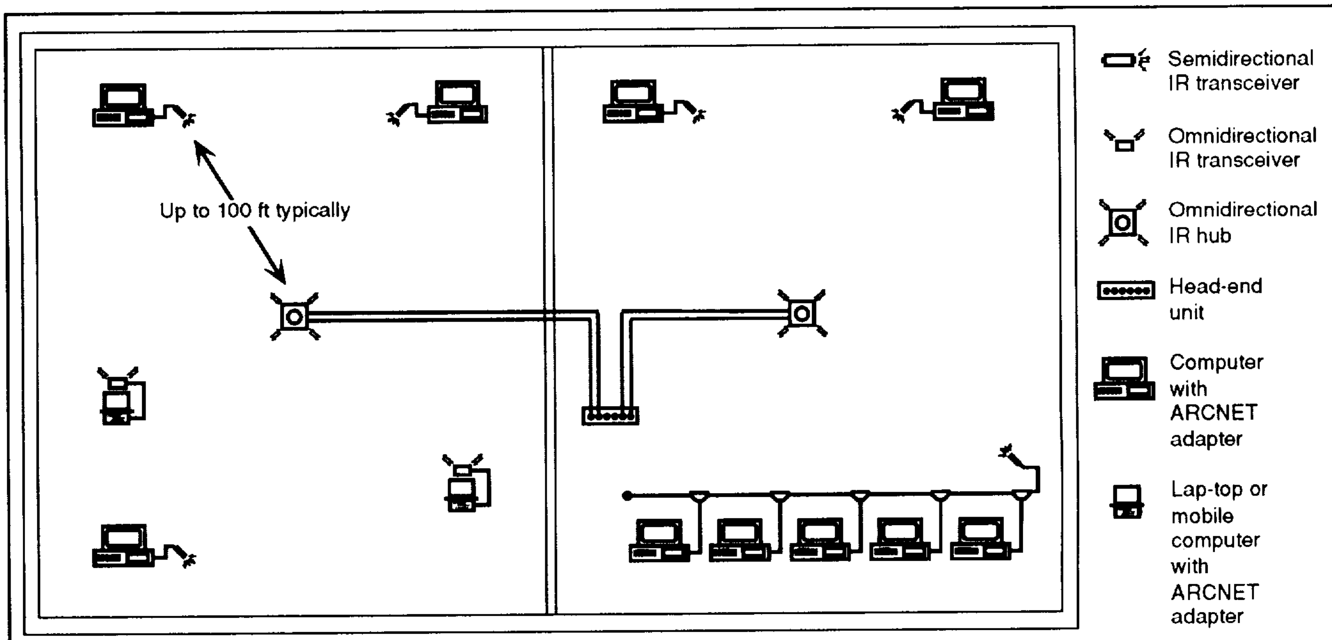
The Wireless Infrared Data Acquisition System (WIRDAS) was developed as a simple and reliable means of interfacing a personal computer (PC) to remotely located devices. The link is established via free-space transmission and reception of optical energy; therefore, cabling is not necessary. Light-emitting diodes are intensity modulated with a digital bitstream that propagates throughout the enclosed area being used. Some of the energy is received by cheap, efficient photodiode arrays that transduce the optical energy back into electrical waveforms.

The hardware was built in two versions to accommodate the two general uses anticipated: (1) for transceiving serial commands and data at rates of up to 19.2 kbaud using the RS-232 link protocol widely used in PC applications, and (2) to transceive commands and data using the ARCNET protocol. ARCNET is an accepted protocol for implementation of local area network (LAN) topologies and operates at 2.5 Mbps.

PCs or other special-purpose nodes equipped with standard ARCNET controller cards may be connected directly to the system miniature infrared (IR) transceivers located at each node. These transceivers communicate wirelessly with ceiling-mounted IR hubs (one or more) that repeat each received transmission (much like a "broadband LAN"), thereby extending and distributing the transmission over a wide area or multiple areas. The IR hubs are miniature, ceiling-mounted devices that, in effect, form a single "distributed" IR hub and are all connected by cable to a common head-end unit, which powers the hubs and processes and repeats the signals received (fig. 1).

This hardware is expected to greatly increase flexibility and lower cost in office (and therefore LAN) rearrangement. As there is little cabling involved, all that is required is to re-aim the PC directional transceiver to one of the ceiling-mounted IR hubs after the rearrangement process. Acceptance testing of both delivered prototypes validated the performance of the concept, and the hardware is now offered in the product line of the developer.

This work was jointly funded by the NASA/ Johnson Space Center Technology Utilization Office and Wilton Industries, the contractor.



Note: Two-room system shown. Up to 24 rooms can be accommodated. For rooms larger than 40,000 ft², more than one hub may be required.

Figure 1. IRPLEX no-cable hub system for ARCNET.

Image-Based Tracking Systems

PI: T. E. Fisher/EE
Reference: SST 11

The NASA/Johnson Space Center is expanding its traditional tracking systems capabilities to include the use of imaging sensors for tracking. These sensors include passive devices, such as simple video cameras, and active devices, such as laser radars. Typical applications for this technology include automated robotic systems autonomous rendezvous and capture (AR&C), satellite servicing, and autonomous planetary landing systems. The Tracking and Communications Division Tracking Techniques Branch has an active program in image-based tracking. State-of-the-art hardware is being used to develop new image-based tracking systems to allow cheaper tracking systems for the new breed of smaller autonomous space vehicles.

The research emphasis during 1991 has shifted away from the "blob" analysis and neural net classifiers toward the use of stereo vision as a 3-dimensional sensor for AR&C. The in-house effort is concentrating on the design of appropriate docking targets and the image-processing algorithms necessary to identify these targets in the presence of anticipated background "noise." This background noise can include complicated spacecraft structures; specular reflections; and Earth, lunar, and star backgrounds. Once the target is segmented from the background clutter, the stereo cameras provide a range estimate to each known point on the target. With these ranges and the known geometry of the target, the range and attitude of the target vehicle can be determined.

The out-of-house effort on stereo vision has concentrated on advanced architectures that will improve the speed and accuracy of the stereo measurements. NASA completed a Phase I Small Business Innovative Research (SBIR) contract entitled "Log Polar Binocular Vision System" (see separate task description) with Transitions Research Corporation (fig. 1). This work utilizes the log polar coordinate systems in the stereo cameras (see the "Programmable Image Remapper" task description). These coordinate systems (1) provide a reduced number of pixels that must be processed per image, (2) maintain high resolution at the center of the field of view (usually where the excitement is), and (3) reduce the complexity of the processing per pixel because of the log polar tessellation pattern of the pixels. The resulting system should yield a successful stereo vision system with computational requirements small enough to support real-time spaceborne applications. Such a system has been proposed for a Phase II follow-on to the Phase I SBIR contract.

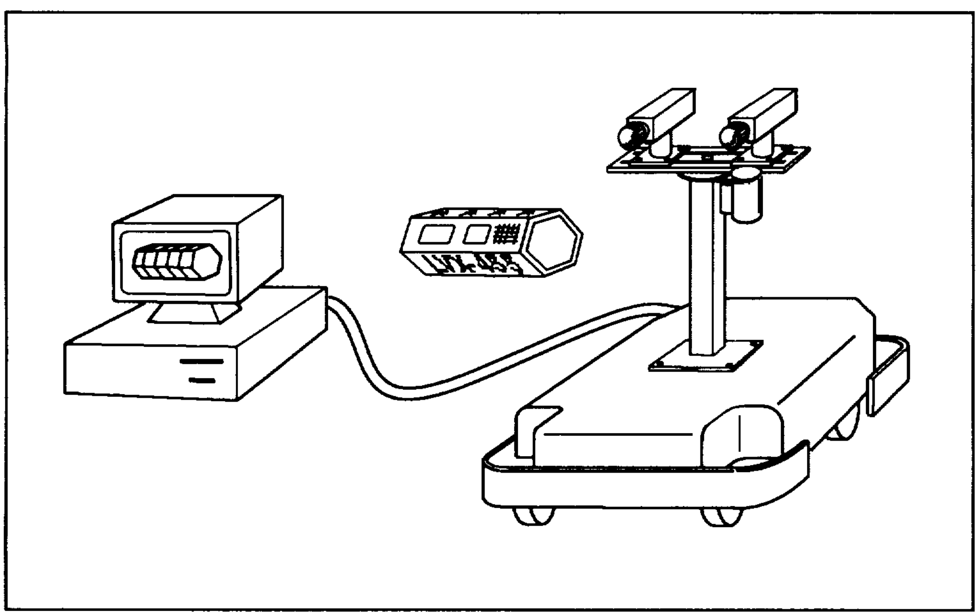


Figure 1. Shape inference from log polar binocular disparity.

Optical Communication Through the Shuttle Window

PI: J. L. Prather/EE
Reference: SST 12

In January 1987, NASA Headquarters Advanced Program Development (code MD) funded a 3-year program to design and develop an alternative communication link between the crew cabin and the payload bay on the Orbiter. This alternate system will allow payload specialists to communicate with their particular payload independently of the Orbiter system and will also increase the potential bandwidth for communication between the crew cabin and the payload bay. Fiber optics will be utilized in this system to achieve these goals. Optical fibers, transmission mediums for light, will guide light that is modulated with the appropriate electrical test signals to the cabin side of the aft window. There the light, with the information stored in its intensity levels, will shine through the window and be received on the payload bay side of the window by a fiber that guides the light to a box in the payload bay. The box acts as a repeater station for the test signals. Upon leaving the payload bay box, the light will return to the optical communication through the Shuttle window (OCTW) crew cabin box via fiber-optic cable and the aft window. This box will evaluate the integrity of the optical link. Two subsystems will be a part of the OCTW system: a 200-Mbps emitter coupled logic digital link and a video link.

The hardware was completed and demonstrated on orbit in FY91 (fig. 1). The hardware performed well after initial installation problems were corrected (fig. 2). The alignment mechanism was sensitive to changes caused by thermal expansion when passing between day and night portions of the orbit. This sensitivity required the crew to make a minor lateral adjustment of the fiber-optic coupler during each day-night transition. The automatic gain control and bit error rate data, which were being stored to measure system performance, were lost because of a configuration error with the video tape recorder (VTR). The audio switch was to be set to the hot-microphone mode so that the data could be recorded on the audio channel of the VTR. Instead, the switch was set to the push-to-talk mode, and the data were never received.

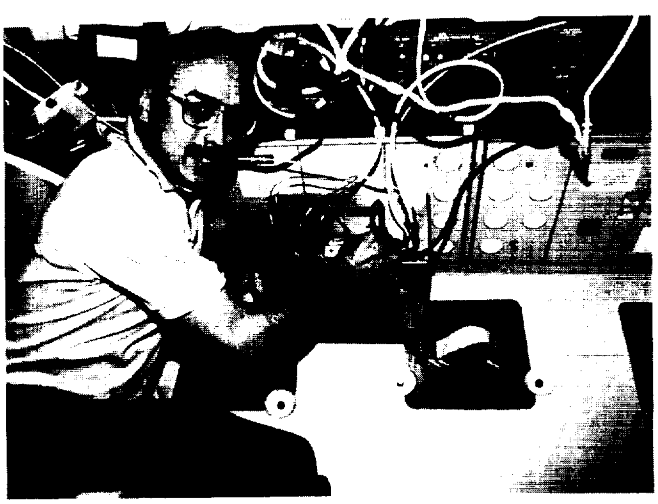


Figure 1. Crew operation of OCTW cabin unit.

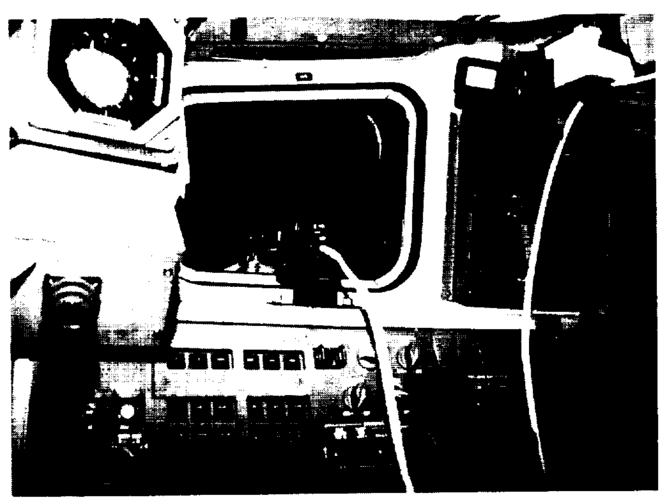


Figure 2. OCTW coupler Orbiter window installation.

Laboratory Demonstration of Innovative Compact, 3-Dimensional Imaging Sensor

PI: K. F. Dekome/EE
Reference: SST 13

The need for compact, reliable, cheap, and accurate sensors to spatially map environments spurs continual development of innovative ideas in this area. One such concept is that of turning a gated image-intensifier tube into a ranging device, using the applied gate voltage as a demodulator input that demodulates the reflected energy from a target; this energy is in turn irradiated by a laser diode modulated at the same frequency. Image-intensifier tubes are used in applications such as low-light-level television cameras and night-vision goggles to amplify the generally weak light energy being reflected by a scene. An integral component of this ranging device is a microchannel plate (MCP) that will amplify the signal current generated by a differential area of photocathode by as much as 1 million times while maintaining the relative irradiance pattern across the photocathode (caused by the scene being imaged on the photocathode through a lens). This amplified electronic image then strikes a phosphor screen that radiates monochromatic light (generally green) in direct proportion to the electronic image, and is then viewed by an eye or a camera. Modulating a laser diode, which then irradiates a scene, generates a relative phase shift directly proportional to the range to objects in the scene. This phase shift is sensed through the demodulation process on the MCP and the integration (low pass filtering) caused by the phosphor screen and camera. It is anticipated that range resolutions on the order of several centimeters can be achieved using this technique.

A simple demonstration of this concept was achieved under a Phase I Small Business Innovation Research contract by the proposer, Daedalus Enterprises. The Phase II proposal currently is being evaluated.

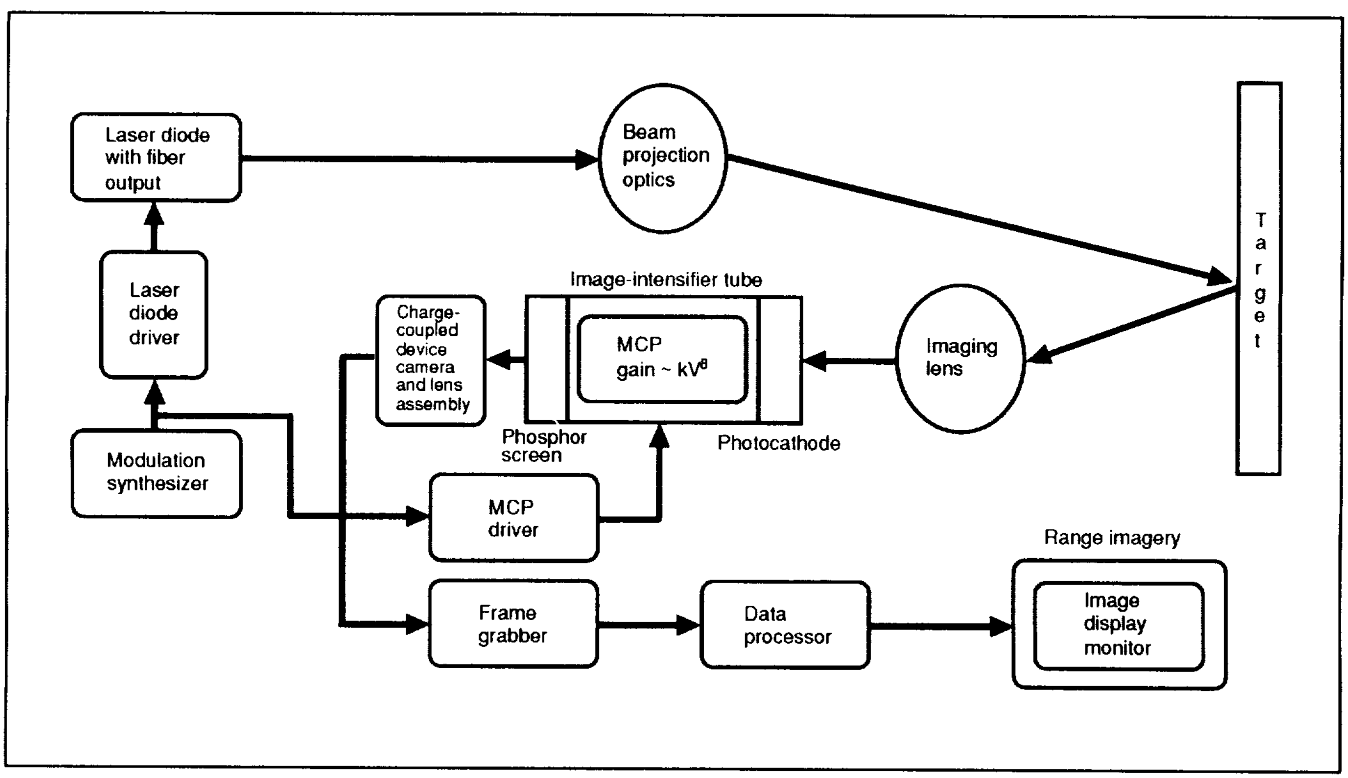


Figure 1. Geometric transformation domains.

Exponential Grids in Robotic Vision

PI: R. D. Juday/EE
Reference: SST 14

Polar exponential sensor arrays sometimes have advantages over conventional Cartesian raster-imaging sensors when a wide field of view, high central resolution, and rotation and zoom invariance are desirable. As a sensor translates in a 3-dimensional space of imaged objects, image flow (the local velocity vector field of features in the image) can become pure translation for planar surfaces normal to the motion of the sensor platform (figs. 1, 2, and 3). Further, making time-to-collision maps (which become distance maps when speed is known) becomes a linearized problem after a polar exponential transform. Finally, the 3-dimensional spatial resolution cells for digital stereopsis have natural expression, following transformation from a Cartesian to a polar exponential coordinate system, with positive ramifications for economy in the determination of disparity and inference of distance.

Under a Small Business Innovative Research (SBIR) contract, Transitions Research Corporation delivered a system, a mobile tracking robot that has built-in vision based on the polar exponential grid. The robot demonstrates several scenarios of interest to space vision. They include use of optical flow for hazard avoidance and simplified pattern recognition for outlines of thresholded objects. Results of several NASA/Johnson Space Center-sponsored research efforts in both hardware and algorithms are incorporated in the technology. During FY91, two new SBIR contracts were initiated to take the log polar transformations into practical application: binocular stereo, in which disparity as a function of distance has a particularly simple expression, and the log-Hough transformation, which is convenient for tracking an object appearing in sequential video frames. Both were concluded with quite satisfactory results, and the Tracking and Communications Division has recommended one of them (stereo) for further development in a Phase II contract.

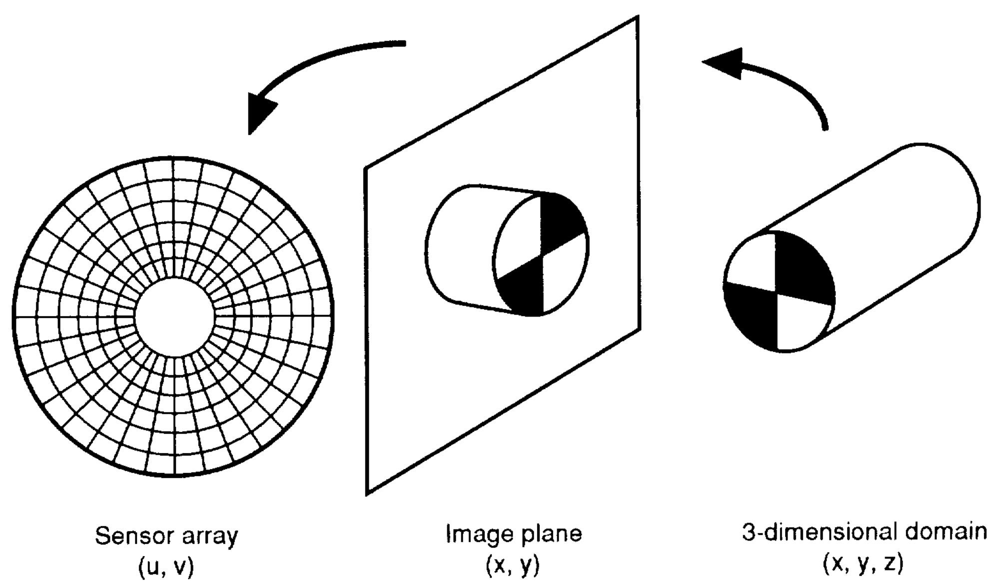


Figure 1. Geometric transformation domains.

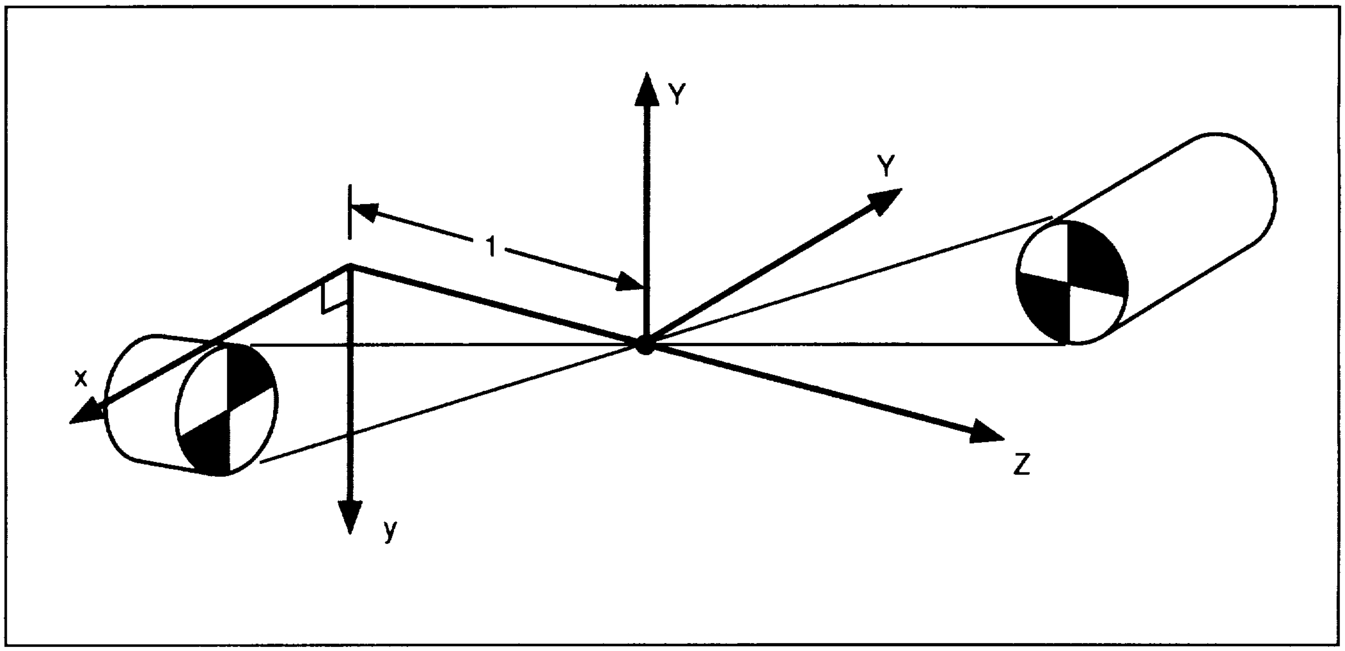


Figure 2. Projection of 3-dimensional objects onto image plane.

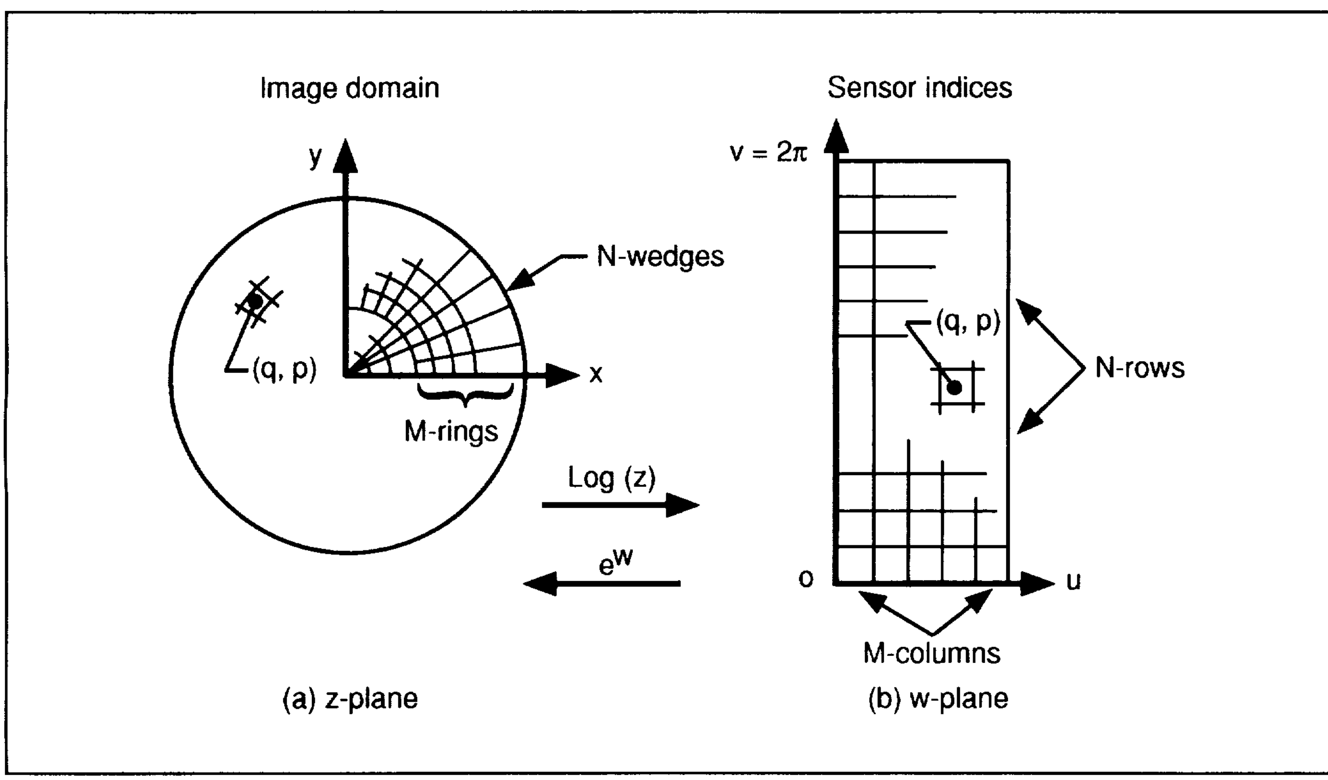


Figure 3. Conformal mapping from image coordinates to sensor array.

Hierarchical 3-Dimensional and Doppler Imaging Laser Radar

PI: J. L. Prather/EE
Reference: SST 15

The purpose of this Small Business Innovative Research project is to develop an improved 3-dimensional imaging laser radar (ladar). The ladar will be applied to robotic vision and spaceborne target tracking for rendezvous and docking, remote manipulator and autonomous robot operations, satellite servicing, proximity operations, and lunar/planetary landing.

This 3-dimensional mapper provides Doppler, as well as range and intensity images and programmable/adaptable scans, consisting of a fine-resolution fovea and lower resolution peripheral vision (patterned after the human eye). The high resolution can be placed anywhere within the sensor field of view (FOV), according to the region of most interest, while the lower resolution peripheral vision provides for simultaneous monitoring of other objects or target features and obstacle avoidance. The Doppler imagery provides range rate information for rendezvous and docking, provides an additional discriminator for object recognition, and could be useful in identifying the rotation axis of a spinning satellite to aid in approach and grappling. In addition to these high-resolution and low-resolution capabilities within a ±10° field of regard, a peripheral minigimbal (PMG) will provide hemispherical coverage.

The Phase II hardware was completed in FY91 and is currently on loan to the vendor for use in developing a matching vision processor that is being funded by the U.S. Army. The hardware, including the vision processor, will be delivered in FY92 for integration into the 6-degree-of-freedom test facility. After integration, the system will be demonstrated to the NASA/Johnson Space Center and U.S. Army personnel. An in-depth evaluation of the sensor performance will occur in FY92.

TABLE 1. PHASE II SYSTEM PARAMETERS

Feature	**Characteristic**
Carbon dioxide ladar	2 W, 10.6 μm, heterodyne
Registered imagery	Range, velocity, intensity, visible video
Peripheral scan	Hemispherical coverage — PMG
Foveal scan	±20° wide field of view (WFOV)/ narrow field of view (NFOV)
Angular resolution	0.5 to 12.5 mrad
Transmitter waveform	Continuous wave (CW), amplitude modulation (AM), frequency modulation (FM), AM/FM
Maximum range	3000 ft: skin targets, NFOV
Pixel format	1Hz to 100 kHz, $(1024)^2$ programmable
System controller	Transputer network (12)
Sensor head size	1 ft^3
Electronics size	19-in. rack, 10 in. high

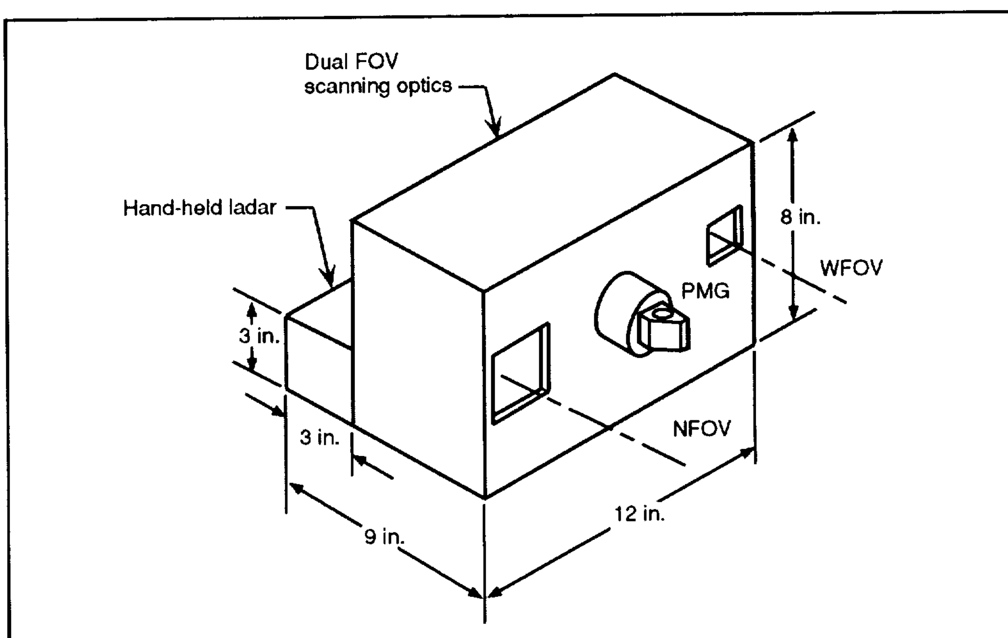


Figure 1. Phase II prototype hand-held ladar/dual FOV scanning package.

Optical Correlation

PI: **R. D. Juday/EE**
Reference: **SST 16**

Optical processing offers the possibility of faster, lighter weight, simpler vision systems for some applications that do not require the great power and generality of vision by digital image processing. The in-house investigation is advancing on several fronts: the development of advanced spatial light modulators (SLMs); the development of special filtering algorithms for use in phase-only optical correlators, including impulse deconvolution and correlation pattern shaping; and geometric image remapping.

The Tracking and Communications Division is directing work for each of these activities performed by several organizations, including the National Institute of Standards and Technology, various military organizations (Army Missile Command, Army Human Engineering Laboratory, Naval Research Laboratories, and Rome Air Development Center), a large number of universities (two University of Houston campuses, University Park and downtown; Carnegie-Mellon University; Tennessee Technological University; the University of New Hampshire; and the University of Missouri at Kansas City), and other NASA Centers (Ames Research Center, Langley Research Center, and the Jet Propulsion Laboratory).

The optical processing of video data, using SLMs in a real-time optical correlator (fig. 1), is being developed for use in robotic vision and proximity operations, such as docking, autonomous landing, and stationkeeping. The system should be capable of identifying a specific object (or feature) and determining the azimuth, elevation, range, roll, pitch, and yaw of the object. The hybrid system will make use of the high speed of optical correlation by transferring optical filters to the SLM at a rate of 120 filters per second from a digital computer that will evaluate the correlator output from the charge coupled device (CCD) imager and choose the next filter.

To realize the benefits of such a system, sets of filters and logical procedures for accomplishing specific tasks are being developed. Current work includes the evaluation of filters designed for the estimation of an object attitude on various hardware configurations in the Image-Based Tracking Laboratory.

Several advances were made during this fiscal year. A filter theory was developed to include realistic physical limitations of SLMs and correlation detectors in the optimization process. Lead articles were published on optimizing signal-to-noise ratio in the presence of colored input noise; the article entitled "Saturated Filters" was accepted by the *Joint Optical Society of America, A Journal of the Optical Society* in October 1991; and the article entitled "Optimum Real Correlation Filters" was published in *Applied Optics.* A method to attain signal-to-noise ratios from a filter, limited to real values that are guaranteed to be within 3 dB of the optimum, was described in an article entitled "Design of Phase-Only, Binary Phase-Only, and Complex Ternary Matched Filters With Increased Signal-to-Noise Ratios for Colored Noise," which was published in *Optics Letters.* U.S. patent 5,029,220, entitled "Optical Joint Correlator for Real-Time Image Tracking and Retinal Surgery," was issued on a NASA/Johnson Space Center method of image stabilization. What is believed to be the Nation's first optical correlator, with live input and live filter using commercially available liquid crystal television modulators and operating in a continuously variable mode, was constructed. (This work has not yet been published.) Other work continues.

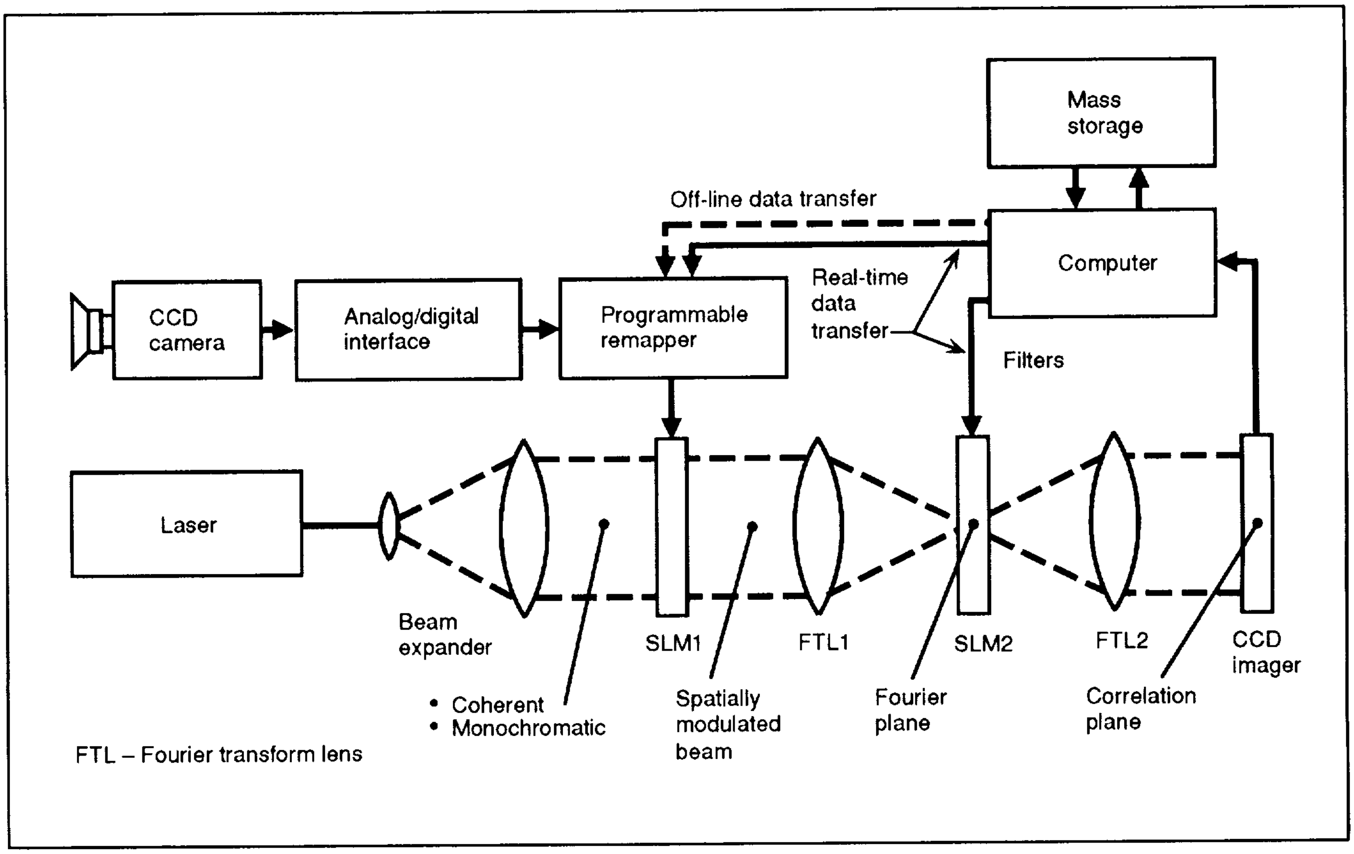


Figure 1. Optical correlator.

Autonomous Guidance

PI: **Gene McSwain/EG221**
Reference: **SST 17**

During 1991, the focus of this task was on making improvements to the powered flight portion of the Shuttle return to launch site abort mode. Heating constraints during the powered flyback and loads constraints during the entry are contributing to limiting the maximum allowable payload weight of the Orbiter. Improvements in the powered flight can alleviate, to some extent, both these areas of concern.

A modification of the powered flight guidance was developed at Charles Stark Draper Laboratories and was evaluated with high-fidelity 6 degree-of-freedom simulations by NASA/Johnson Space Center subcontractor McDonnell Douglas and by Rockwell-Downey. This candidate change request reduced flyback heating and dispersions at main engine cutoff (MECO) by replacing the current open loop pitchdown just prior to MECO with a closed-loop guided pitchdown. Including the pitchdown in the guidance prediction allowed tighter control of the cutoff conditions and also allowed a lower flightpath angle to be used at the beginning of the pitchdown, raising the minimum altitude and, in turn, reducing the heating. Although the candidate change did, indeed, achieve the desired improvements, it was a large modification and will be expensive to validate.

Follow-on work will simplify the change as much as possible while still preserving the benefits and will examine the phase of flight just prior to turning around, which also has a strong influence on flyback heating.

Control Technology

PI: **John Sunkel/EG1**
Reference: **SST 18**

For control of spacecraft, testing of the state space self-tuning adaptive control algorithm was conducted on the Space Station attitude control simulator. Adaptive system identification and control techniques based on artificial neural networks were developed. For computational control, the Space Station computational controls workstation (SSCOMP) was delivered to NASA/Johnson Space Center (JSC).

The SSCOMP is an integrated hardware/software platform for Space Station guidance, navigation, and control analysis. The approach is based on using state-of-the-art flexible multibody dynamics algorithms coupled with parallel processing techniques. The SSCOMP uses an integrated set of software tools to provide a user-friendly, productive environment and contains a sophisticated graphics and 2-dimensional/3-dimensional solid modeling package that can be used for animation purposes.

The SSCOMP represents a quantum leap in simulation technology.

For lifting body approach/landing trajectory analysis, an agreement was made with the Langley Reasearch Center (LaRC) to evaluate Langley's proposed lifting body Personnel Launch System candidate, referred to as the HL-20. In 1991 the Navigation Control and Aeronautical Division modified the existing Shuttle engineering simulation to represent the HL-20 configuration.

The JSC HL-20 simulation continues to evolve with capabilities currently expanded to include flying in the terminal region from Mach 2.5 through rollout in either the auto or the manual mode. The addition of a rollout capability required implementation of a gear/tire, slapdown, and rollout dynamic math model derived from the current Shuttle simulation model. In addition, preliminary trajectory shaping from deorbit down to terminal area energy management (TAEM) has been started. The implementation of this phase into the simulation is planned to occur in early 1992.

Analyses were performed on the HL-20 aerodynamic data and trajectory to determine capabilities from Mach 4 as well as to evaluate vehicle performance during TAEM.

A 1991 year-end report was written documenting HL-20 strengths and deficiencies with comments citing possible vehicle changes for improving performance.

Figure 1. The SSCOMP presents the first integrated environment for the modeling, simulation and analysis of Space Station guidance, navigation, and control. Using highly efficient computational algorithms combined with an ultra-fast parallel processing architecture, the workstation makes real-time simulation of flexible body models of the Space Station possible.

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Advanced Flight Data System Architectures

PI: **David Pruett/EK11**
Reference: **SST 19**

The original Research and Technology Objectives and Plans proposal was divided into four different tasks: Requirements Generation, Software Architecture, Hardware Architecture, and Mission Unique Specifications.

Task 1 was begun and completed by Boeing during the last 3 months of FY91. Some funding was given to the Lockheed Engineering and Sciences Company (LESC) to augment in-house funding to work on tasks 2 and 3 in preparation for continued Boeing funding in FY92. Boeing delivered two documentation packages. The first package was a set of detailed performance requirements for each reviewed potential vehicle type. The second package was a summary of the entire set of performance requirements in the form of statements that are to go into a document being drafted as the final output of this activity. The contents of the two packages are depicted in the workflow diagram (fig.1). The requirements were divided into several matrices. The first matrix identified mission requirements by flight elements. The second matrix identified several classes of vehicle types to reduce the number of cases to study. Matrix 3 identified the service and interface requirements by document section. These contents were then transformed into statements for the draft requirements document. No work was done on task 4.

Tasks 2 and 3 were begun and partially completed by LESC during FY91. They were able to complete a fairly detailed assessment of the software architecture, in terms of functions and interfaces, during FY91. The software architecture work identified six major areas where a Flight Data System provides services: standard data services, data system manager, operating system, data base manager, network services manager, and space operations control. Detailed functions within each of these areas were defined, and potential interfaces were identified. Work on the hardware architecture had progressed to the point of identifying major hardware components and their interfaces as well as seven types of interfaces that needed to be specified within the architecture.

Work in FY92 will be funded through division funds and will continue the work of developing the hardware and software architecture to the point where standards can be identified for each interface.

The following figure shows the Space Data System Services requirements development path followed by Boeing, the initial software and hardware architecture, and the seven interface types identified.

Standard Data Services Manager

- **Standard services data acquisition controller**
  - Data bus services
  - Sensor and effector input/output
  - Sensor pre-processing services
  - RODB write
  - RODB link
  - Journal manager
- **Standard services data distribution**
  - RODB read
  - RODB link
  - Caution and warning processing
  - Telemetry processing
  - History processing
- **Reports generator**
  - Tables
  - Forms
  - Outputs

Data System Manager

- **Configuration manager**
  - Upgraded software tables change management
  - Reconfigure hardware and software
  - Maintain system configuration
- **Timing service controller**
  - Monitor timing service
  - Automatic timing reconfiguration
  - Manual timing reconfiguration
  - Resynchronize timing
- **Data system initialization, startup, and reconfiguration**
  - Identify software to be loaded
  - Load and initialize software
  - Terminate software
  - Process initial and reloaded requests
- **DSM health, status, and FDIR controller**
  - Collect health status and failure data
  - Process health status and failure data
  - Automatic reconfiguration
  - Manual reconfiguration
  - Update history data base

Operating System

- **OS Kernal**
  - Process management and control
  - Initialization and configuration management
  - I/O management
  - Memory management
  - CPU management
  - Utility services
  - Privacy and security management
- **ADA RTE**
  - ADA compiler support
  - ADA/non-ADA mixed environment
  - ADA real-time POSIX compliant environment
- **OS/RTE extensions**
  - Real-time applications task control and communications
  - ADA multi-program management
  - Inter-process communication
  - Internal bus management
  - OS/RTE initialization and self test
  - Precision time distribution
- **Nonstandard processor services**

Data Base Manager

- **File service controller**
  - Structured file services
  - Distributed file services
  - Resource management (in mass storage unit)
- **Distributed file transfer service controller**
  - Internal system node transfers
  - Ground archives (in each node)
- **File transferring access and management controller**
  - External node transfers
  - Virtual/real file mapping (in mass storage unit)

Network Services Manager

- **Network service controller**
  - Network command verification
  - Network stack controller
  - Network queue managment
  - Stack
- **Network manager**
  - Network coordinator
  - Network status directory
  - Network fault detection
  - Stack layer management
  - Network security managment
  - Network performance status
- **Remote operator**
- **Network directory service controller**
  - Directory user agent
  - Directory system agent
  - Directory information base
  - Directory information tree
- **Network association controller**

Figure 1. Space data system services requirements architecture.

Full Color Flat Panel Display

PI: **Andrew Farkas/EK6**
Reference: **SST 20**

The object of this research program is to develop a sunlight readable, large area, high-resolution full color, flat panel alternate current (AC) plasma display with full video interface. Since the proposed display is to be AC plasma, it has the advantage of an ultrawide viewing angle, operation over extreme environmental conditions, and a very high operating life. This type of display can be made a very large, 2-m diagonal, and will require less power than many other types of color flat panel displays.

Phase I of the program demonstrated both the feasibility and the high level of performance possible from photoluminescent color AC Plasma Display Panel (PDP) based on a double substrate color structure. Also demonstrated was the feasibility of a dot matrix multi-color AC-PDP operating in the memory mode with both improved memory margin and high luminosity.

Phase II of the program demonstrated a 17-in. diagonal full-color AC plasma display. This display has an optical resolution of 26 pixels per inch, a picture resolution of 431 × 256 pixels, and a color palette of 262,144 hues, based on 64 levels of gray per color. Incorporated into this display is a standard red-green-blue video interface and an RS-170A video interface that operates at 60 frames per second. A picture resolution of 320 × 240 full color pixels and an optical resolution of 42 pixels per inch were also demonstrated on a smaller 9.6-in. diagonal panel. Display brightness and reliability have been improved due to redesigns and optimization of both waveform generation circuitry and the power recovery electronics.

Activity on this research program has been almost completed. Photonics is currently assembling a 17-in. diagonal full-color display for delivery. The panel will be available in our laboratory for test, evaluation, and demonstration. Photonics is also working with various display users, including commercial and military, to market their new color AC plasma displays.

Space Station Heat Pipe Advanced Radiator Element II

PI: **Steven D. Glenn/EC2**
Reference: **SST 21**

Development of high-capacity heat pipe radiator systems has been ongoing for some time to support requirements for large space structures such as Space Station Freedom (SSF). Heat pipe radiators offer several distinct advantages over conventional heat-rejection methods such as modularity and simplicity. The Space Station heat pipe advanced radiator element (SHARE) was the first attempt to demonstrate the heat-rejection capabilities of a 51-ft, high-capacity, monogroove heat pipe in a zero-g environment aboard STS-29. The SHARE flight identified detailed design deficiencies and, due to the criticality of the active thermal control system to SSF, a reflight—designated SHARE II—was proposed and flown aboard STS-43 (fig. 1).

Major design differences exist between SHARE and SHARE II; however, the majority of the SHARE hardware was reused with necessary modifications. Two new 6-in. wide heat pipe radiator panels were fabricated to attempt to solve the SHARE deficiencies utilizing different design techniques. Lockheed Missiles and Space Corporation provided a "graded groove" extrusion, while Grumman Aerospace Corporation again utilized the "monogroove" extrusion with internal modifications. Another significant change involves the length of the radiator panels. An SSF design change from 43-ft to 22-ft radiator panels dictated that the active portion of the SHARE II radiator panels be decreased to 22 ft. The capability to operate the heat pipe radiator panels in a simultaneous but independent mode was required for flight and meant that extensive modifications to the heat pipe instrumentation and control system (HPICS) were required.

Following the delivery of hardware, 1 week of thermal-vacuum certification testing was completed in late January 1991 in chamber A, building 32. Both the flight and backup heat pipe radiator system (HPRS) assemblies were tested. To accommodate this, the HPICS was utilized in conjunction with the flight HPRS, while ground support equipment controlled the second HPRS. All heat pipes performed as expected with approximately half of the test duplicating the actual mission profile, and the remaining test time was allocated to investigate the heat pipe response to freeze/thaw cycles and reaction to transient heat loads.

Modal testing and random vibration testing of the SHARE II structural test article was completed in November 1990, and math model correlation of the test results to the structural model was completed early in 1991. A change in the HPICS carrier from an adaptive payload carrier (APC) to an increased-capacity APC was made as a result of structural analysis that indicated insufficient capability of the APC. The SHARE II configuration was certified shortly thereafter for a total of five flights.

The STS-43 mission was extended from 5 days to 9 days, and as a result, the SHARE II community requested and was allocated three additional data takes that increased the severity of the transient heat load.

The SHARE II hardware was shipped to NASA/Kennedy Space Center (KSC) at the end of March, and off-line preparations and functional testing were completed in early April. Following turnover to KSC, cargo integrated test stand interface verification testing (IVT) to verify payload-to-Orbiter telemetry was successfully completed. Installation into OV-104 at the Orbiter Processing Facility was completed in May, with the HPRS alignment completely shortly thereafter. The IVT testing prior to rollout and at the pad prior to launch confirmed that all SHARE II telemetry was nominal.

Flight operations began on day 2 of the mission and continued throughout the 9-day flight. Due to the relatively smooth operation of the flight, SHARE II was granted approximately 50% more time (approximately 60 hours total) for heat pipe operation. Primary objectives achieved included passive priming of the heat pipes, reprime following a forced deprime, and steady-state operation of the heat pipes while subjected to heat loads varying from 0 to 385 W. Continuous operation of the heat pipes for a maximum of 16 hours at various power levels was also demonstrated, as was the ability of the monogroove heat pipe to successfully ingest bubbles into the evaporator while under load. Although both heat pipes operated successfully, data from the flight indicate than the monogroove heat pipe is a more robust design that the graded groove design. Flight hardware was returned to the NASA/Johnson Space Center following STS-43, and current plans call for a possible reflight with longer radiator panels.

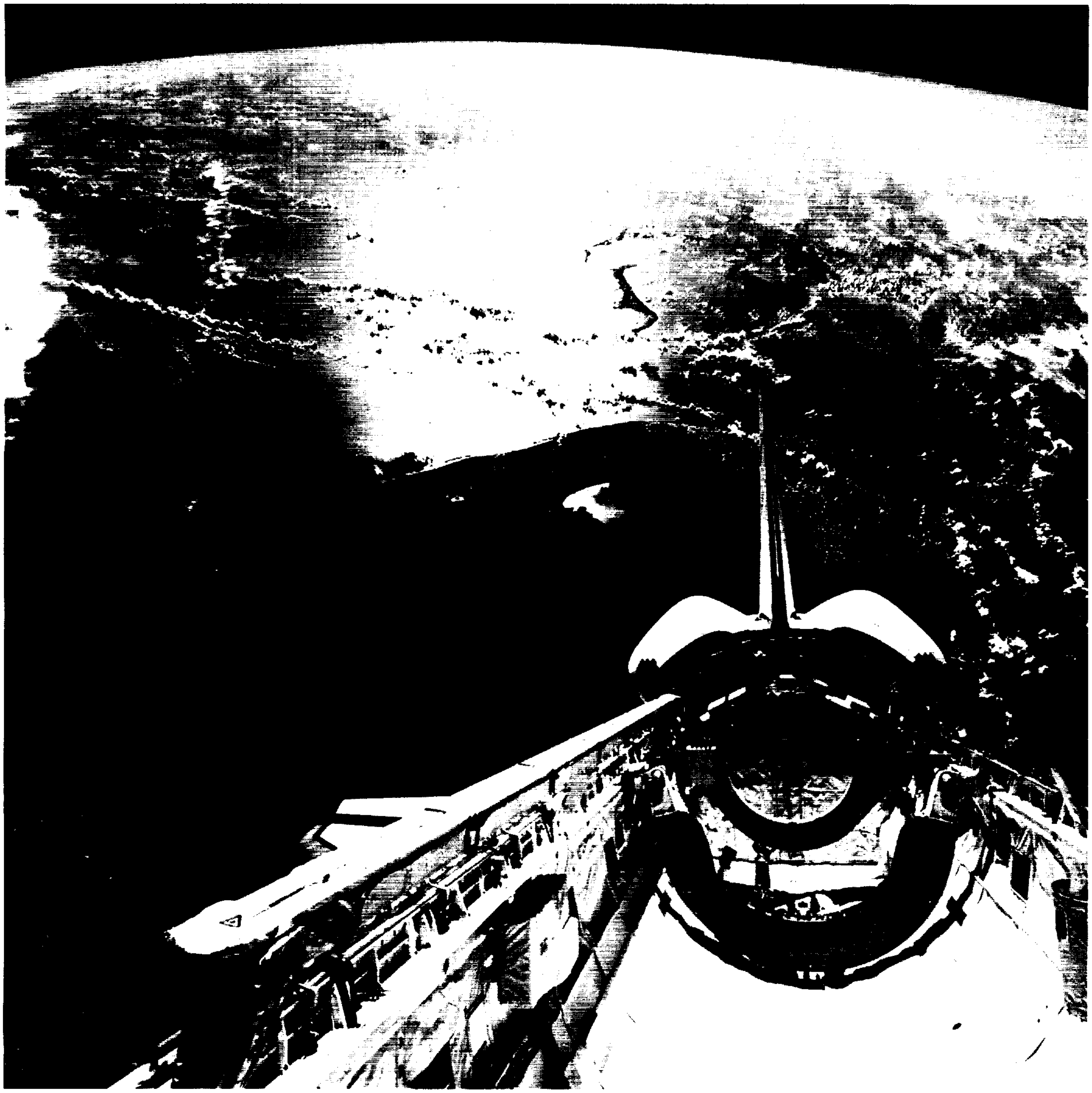

Figure 1. The SHARE II payload aboard STS-43.

Investigation of Long-Term Stability in Metal Hydrides

PI: Patricia A. Petete/EC2
Reference: SST 22

It is recognized that future missions to the Moon and to Mars will require the use of a heat pump to reject moderate temperature habitat waste heat. Metal hydride heat pumps operate on the principle of absorption and desorption of hydrogen between two hydride containers. These chemical heat pumps elevate the moderate temperature waste heat to enable rejection to the warmer environment without the power penalty associated with vapor compression-type heat pumps. High-temperature waste heat from a power source is utilized to regenerate the heat pump.

Since the contract start date of September 1, 1989, this effort has focused on investigating the effects of long-term rapid cycling and thermal aging on metal hydride performance. The effort involved the development and testing of various hydrides by Hydrogen Consultants, Inc. (HCI), and X-ray diffraction testing by the University of Nevada, Reno. Analytical methods, as well as special apparatuses, were developed by HCI for rapid and slow cycling and thermal aging of hydrides. The study focused on two families of hydrides: (1) AB_5-hydrides and (2) vanadium dihydrides, VH_2. Within each family the effects of additives were investigated.

HCI found that cyclic degradation in AB_5-type hydrides [such as Lanthinum-Nickel ($LaNi_5$) and Lanthinum-Gadalinium-Nickel ($La_{0.9}Gd_{0.1}Ni_5$)] varies according to the details of how the specimens are cycled (figs. 1 and 2). For example, AB_5-type hydrides experienced less degradation when exposed to 5000 to 10,000 rapid cycles than they did when exposed to 1500 slow cycles. Thermal aging also plays an important role in the degradation process, as related to time spent at saturated conditions, but is secondary at lower temperatures (below 453 K) to another degradation mechanism such as transformation time. Cyclic degradation of AB_5-type hydrides produces significantly different isotherms than does thermal aging. Thermal aging leads to the loss of the hysteresis band, whereas cycling only mildly reduces the bandwidth.

A new form of cyclic degradation was observed during this study that is peculiar to vanadium-based hydrides. It was observed, through time-lapse photography, that the original material undergoes a physical change. The exact cause of this is not well understood at this time.

The contract end date was March 1, 1991. A no-cost contract extension was granted to HCI for completion of the final report. The final report was received and reviewed by NASA/Johnson Space Center in October 1991. The contract is currently in the final stage of the closeout process.

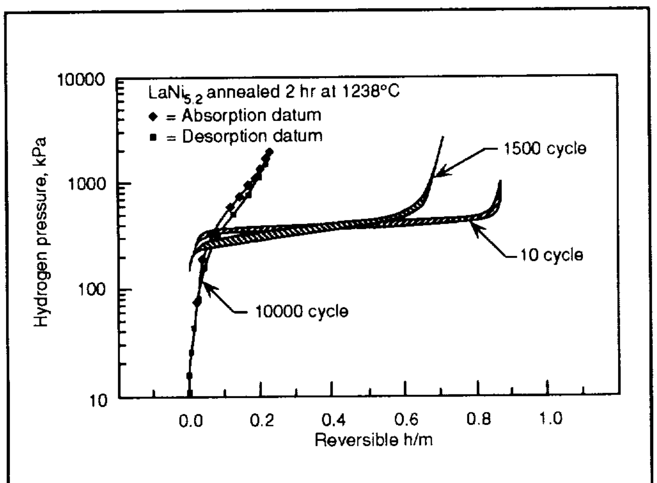

Figure 1. 10,000 cycle absorption/desorption data for $LaNi_{5.2}$-H compared to 10 cycle and 1500 cycle isotherms. All data were taken at 25°C (77°F).

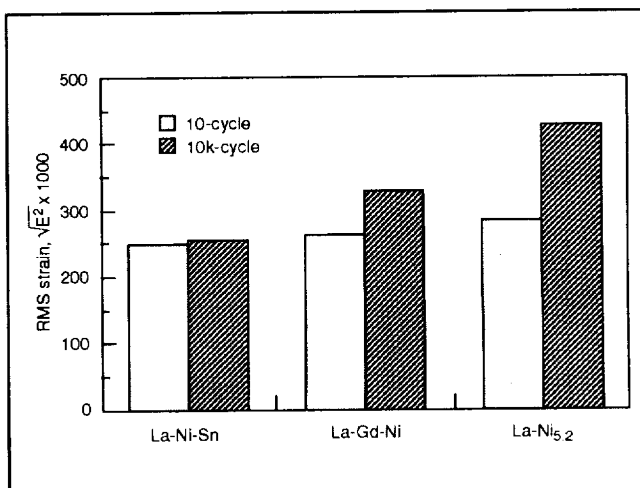

Figure 2. Variation of strain in the 001,002 planes of the hexagonal crystals between 10 and 10k cycles in the SCA.

Making Intelligent Systems Team Players: Design for Human Interaction

PI: J. T. Malin/ER22
Reference: SST 23

Intelligent systems are used commonly to assist humans in the real-time monitoring and fault management of complex space systems, yet humans often have difficulty using intelligent systems. The intelligent systems can be difficult to understand or cumbersome to operate, which complicates task performance. These problems result from deficiencies in design of intelligent systems for effective interaction with humans during joint tasking. The project objective is to make intelligent systems better members of the human-computer team.

This project represents the early stages of an effort to develop human-computer interaction (HCI) design guidance and assistance for intelligent systems. A first step toward this long-term goal has been taken by developing preliminary design recommendations based on the study of NASA intelligent system for real-time monitoring and fault management. A two-volume NASA Technical Memorandum (TM) 104738, has been published, "Making Intelligent Systems Team Players: Case Studies and Design Issues; Volume 1: Human-Computer Interaction Design; Volume 2: Fault Management System Cases." This document describes case study survey results, including descriptions of real-time fault management tasks, human and computer roles, and coordination. It provides recommendations and examples in two complementary design areas: design of the intelligent system and design of displays.

Included in the TM are observations on the process of intelligent system design and on how to deliver design assistance in that context (fig. 1). Recommendations for software engineering methods are being developed to use in designing intelligent systems. HCI will be improved by deriving intelligent system requirements from task descriptions using this software engineering method.

Early project results are being used by intelligent system designers in a variety of NASA programs. They were used to guide development of the Space Shuttle payload deployment and retrieval system decision support system prototype, a real-time data system application. Using this technology, a Space Station Freedom prototype (Space Station module/power management and distribution system) has been modified. This technology is also being used to guide development of fault management systems for unmanned spacecraft systems (similar to the Jet Propulsion Laboratory spacecraft health automated reasoning prototype or SHARP). When used, these methods save system developers time, effort, and cost by reducing the need for redesign and by producing usable systems. Usable intelligent systems enable the productivity gains that are expected from intelligent system technology.

Work continues to extend and refine this technology and to define how it may be incorporated into intelligent system development via design tools, methods, and guidelines. A key goal is to transfer this new technology into intelligent system development projects. Toward this end, a training seminar is being developed. Since intelligent systems for spaceflight control are similar to military aircraft control and process control (e.g., nuclear) systems, this technology is being evaluated by system developers in these areas.

Problem: Determining Quality of Information

Recommendation: Information quality assessments should be provided to the fault management team when available. The objectives of the assessment and the sources of imperfection evaluated in the assessment should be clearly identified.

Problem: Determining Quality of Information

BEFORE – Example illustrating problem:

In this example, the status of three sensors is displayed. The value of this status can be altered by either the Built-In Test Equipment (BITE, quality check built into the sensor) or by the intelligent system. With this presentation format, it is not clear which of these quality tests has determined the value. It is also not clear how a conflict between these two would be resolved.

SENSOR 1	Good	Suspect	Bad
SENSOR 2	Good	Suspect	Bad
SENSOR 3	Good	Suspect	Bad

BEFORE: Poor Presentation of Quality Assessment

Problem: Determining Quality of Information

BEFORE – Example illustrating solution:

In this example, status values from the BITE and the intelligent system are displayed in close proximity to each other. This allows the operator to distinguish between quality tests (since they check different symptoms to determine quality) and to detect conflicts between them (here, BITE has detected Bad status on sensor 1 not detected by intelligent system).

SENSOR 1	BITE	Good	Suspect	Bad
	Int Sys	Good	Suspect	Bad
SENSOR 2	BITE	Good	Suspect	Bad
	Int Sys	Good	Suspect	Bad
SENSOR 3	BITE	Good	Suspect	Bad
	Int Sys	Good	Suspect	Bad

AFTER: Improved Presentation of Quality Assessment

Figure 1. Example of HCI design guidance.

Section V

Space Transportation Technology

Summary

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Space Transportation Technology

The principal activities at NASA/Johnson Space Center (JSC) in the area of space transportation are focused on developing the infrastructure and technology base for human systems, including space servicing and maintenance. Progress made in several of these activities is described in this section.

Future mission operations are anticipated to provide services to the Space Shuttle, Space Station Freedom (SSF), lunar outpost, and Mars missions. The use of telepresence and intelligent systems is anticipated to provide increased safety and cost-effectiveness. Several such implementations involving intelligent/expert systems are in progress at JSC. The Rendezvous Expert System project objective is to develop workstation application software to assist the rendezvous guidance and procedures officers in their flight control duties at the Mission Control Center. The deliverable resulting from the FY91 effort is an application software package called the Rendezvous Software System. This software will add a significant level of automation to the current labor-intensive mode of operation, as well as provide data in more easily interpretable graphical forms. The goals of the project CONFIG Intelligent Modeling and Analysis Automation are to develop automation software for use by domain specialists for both engineering and operations tasks and to promote capture, reuse, and integration of engineering and operations knowledge. The second phase of this project has been completed with the development and demonstration of the CONFIG 2 prototype. This phase integrates qualitative modeling, discrete event simulation, and diagram analysis technologies and embeds them in easy-to-use software with interactive graphics for analyzing dynamic processing systems. In the Mission Evaluation Room (MER) Intelligent Diagnostic and Analysis System project, advanced software is under development for engineers who support the MER during Shuttle flights. Several software tools, called the MER Automated Tool Set for Engineering Systems, have been developed to assist these engineers. During FY91, efforts were focused on providing a software tool set to remote manipulator system engineers. The completion and installation of this model is scheduled for April 1992 for the STS-49 flight.

The JSC Telepresence Workstation Development focuses on the control station architecture to maximize performance of the human/robot system. A breadboard test-bed is under development involving helmet-mounted displays and exoskeleton arm masters. The Johnny 5 robotic mechanism from the movie "Short Circuit" has been selected as the initial controllable robot. The workstation will allow the human to control most efficiently all functions of this slave robot.

The autonomous rendezvous and capture dealt with formulating the hierarchy of customer needs with a potential list of solutions. This analysis resulted in a prioritized list of activities that should be pursued by the rendezvous, proximity operations, and capture community. In another effort, the Exploration Program Autonomous Rendezvous and Docking project completed the approved work by preparing a ground demonstration of the current capabilities of guidance, navigation, and control software, sensors, and docking mechanisms to complete the docking phase of a rendezvous and capture automatically. For the Extravehicular Maneuvering Unit, an electronic cuff checklist prototype was designed, developed, and tested. This battery-powered unit includes an off-the-shelf electroluminescent display, driver electronics, memory, serial data programming port, and three 3-position toggle switches.

The objective of the Shuttle Remote Manipulator System (SRMS) Advanced Force/Torque Control is to provide a demonstrable capability to use force/torque sensing at the SRMS end effector to improve control and identify future upgrades for SRMS. This task was completed successfully during FY91, and a final report is now in preparation.

Under the Rocket Research Long-Life Hydrazine program, a thruster was designed, manufactured, acceptance tested, and delivered by Rocket Research. This program supports the NASA development activity of SSF for evaluating potential long-term hydrazine thruster designs. The thruster was tested at the thermochemical test area of NASA/JSC to identify thruster life and performance under operating conditions similar to those projected for on-orbit SSF propulsion system operations. Results of these and other tests now in progress at Rocket Research are being interpreted and documented.

In the Space Shuttle Primary Reaction Control System (PRCS) project, a thruster-flushing procedure capable of removing nitrate contamination from flight thrusters was developed. This procedure enables NASA to return the thrusters to service without the cost and schedule impact of valve replacement at the manufacturer. A reassessment of both the thruster failure and flushing success rates is planned in the next year to evaluate transfer of this capability to the NASA/Kennedy Space Center.

The Rocket Engine Combustion Stability Task is aimed at developing in-house combustion stability analysis capability with the primary focus on PRCS thruster. A test-bed was designed, and development is now in progress. The tool for this analytical capability is the rocket combuster interactive design computer program developed by Aerojet under a NASA/Lewis Research Center contract.

Several other tasks on Space Transportation Technology are in progress at JSC. One of these is the Aeroassist Flight Experiment, a multicenter, Agency-sponsored technology enhancement experiment, with overall project management at the NASA/Marshall Space Flight Center. JSC efforts involve aerobrake design and fabrication, including science experiment integration, guidance and navigation support, aerobraking trajectory design and mission planning support, the base flow and heating experiment, aerobraking aerothermodynamic and aerodynamic definition, and computational fluid dynamic analytical support. Substantial achievements were reported in most of these areas of JSC responsibility in FY91.

Section V

Space Transportation Technology

Significant Tasks

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Rendezvous Expert System

PI: H. K. Hiers/ER2
Reference: STT 1

The objective of this project is to develop workstation application software to assist the rendezvous guidance and procedures officer (RGPO) in flight control duties at the Mission Control Center (MCC). The project is funded by the Office of Space Flight Advanced Program Development Division, and implementation of the software is being closely coordinated with the Trajectory Operations Branch of the Mission Operations Directorate.

The RGPO is the flight controller responsible to the mission flight director for onboard rendezvous operations and procedures in the MCC. Specifically, the RGPO monitors data displays and makes recommendations to the flight director concerning Shuttle guidance, navigation, and procedure matters during Shuttle missions where a rendezvous with another spacecraft is planned.

The RGPO uses several displays containing digital data received via telemetry from the Shuttle, plus ground-computed data. These data are presented in a textual format requiring careful attention to ensure that correct interpretations are given to the data and data trends. The rendezvous software under development in this project will add a significant level of automation to the current labor-intensive mode of operation and will provide data in more easily interpreted graphical forms.

A result of the FY91 and FY92 development is an application software package called the Rendezvous Operations Software System (ROSS) (fig. 1). The ROSS was implemented in the generic X-Windows programming environment and is designed to operate under MCC workstation executive software. At this time, ROSS is being integrated into a Concurrent (Masscomp) 6600 workstation in the MCC. This activity will be followed by certification testing. Present plans call for the ROSS to be used for the first time in a mission support role on STS-49 in April 1992.

The ROSS performs computations on rendezvous-critical data and presents results in specialized "window" displays used by the RGPO and support personnel for monitoring the progress of the rendezvous. Some of the displays available are

- Graphical presentation of the Shuttle attitude in the local vertical/local horizontal frame of reference.
- Event timer windows for time-to-attitude, time-to-planar crossing, time-to-Vbar/Rbar.
- Caution and warning alarm windows for free-drift alarm, rendezvous radar alarm, and star tracker alarm.
- Plots of Shuttle/target relative motion and reaction control system fuel usage.
- User-interactive trajectory planning window.

A number of ROSS enhancements have been identified for continued development in FY92 and FY93.

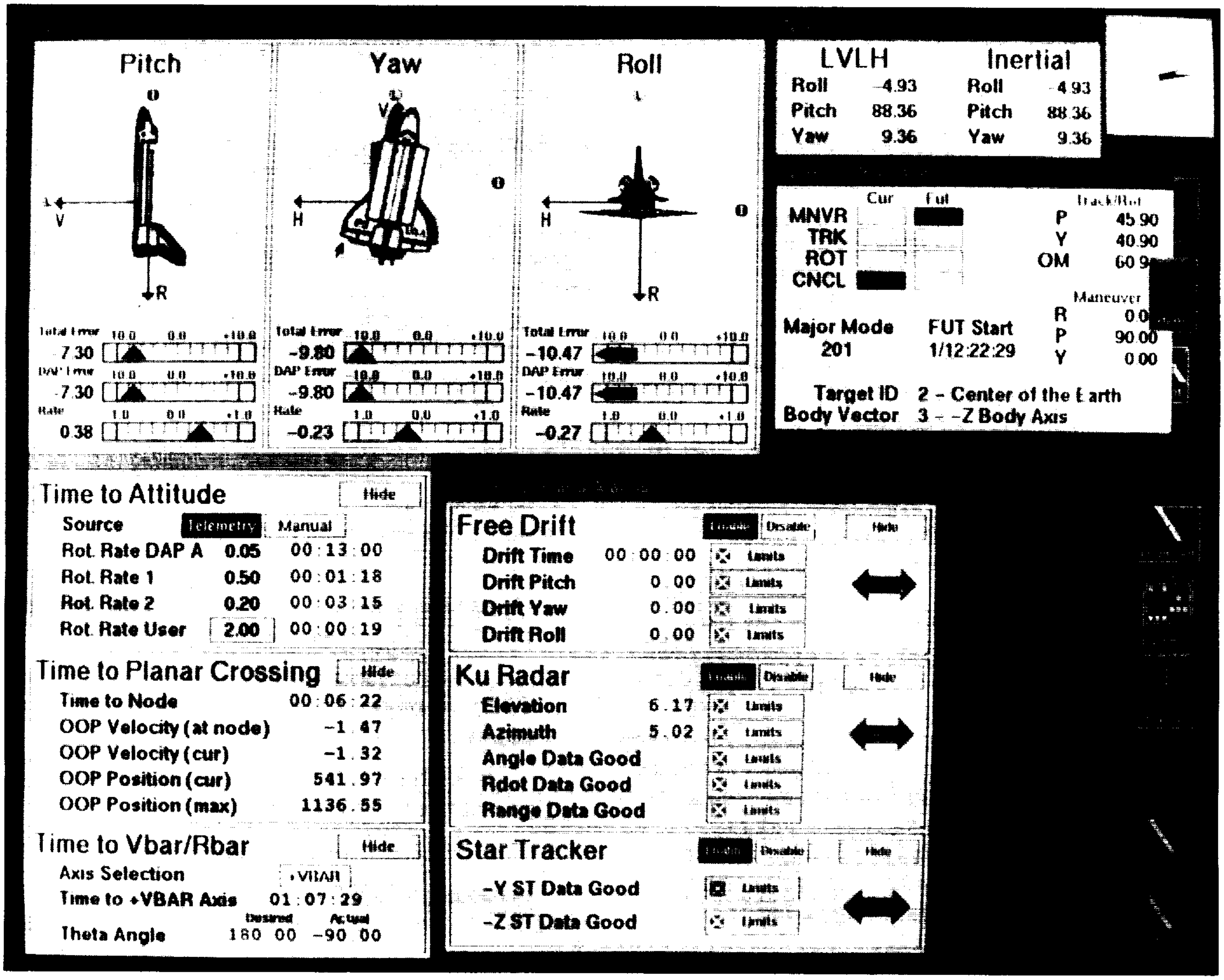

Figure 1. ROSS display.

CONFIG Intelligent Modeling and Analysis Automation

PI: J. T. Malin/ER22
Reference: STT 2

Technology for design automation will enable concurrent engineering processes in NASA programs in the future. Intelligent modeling and simulation and analysis software for design automation can support both engineering and operations tasks and promote capture, reuse, and integration of engineering and operations knowledge. Support for early integrated modeling and analysis of system function, structure, and behavior—along with operations scenarios and procedures—will result in significant reductions in operational costs. Support for integrated modeling of nominal and failed system components and functions will permit early and continuing analyses of failure effects and their interactions with mission operations. Such analyses will result in more robust systems, reduced costs for space system maintenance and repair, and reduced risks due to undetected problems. Reuse of these models in expert systems to support monitoring and fault management of these systems will result in more robust fault management software. This reuse will also aid the timely development and updating of expert system software that is consistent with engineering and operations knowledge.

The goal of this project is to develop such prototype intelligent modeling and analysis automation software, designed for use and reuse by domain specialists throughout the system life cycle. The approach is to incrementally integrate relevant advanced technology, including qualitative system modeling from artificial intelligence, and demonstrate its use in selected operations and engineering analysis tasks. The CONFIG project has developed a flexible modeling and simulation system to support application-based research and development. CONFIG takes an engineering approach with a system that can use a mixture of techniques from several technology areas, thus supporting integration of new model representations, methods, and algorithms for simulation and analysis. To support application and evaluation, CONFIG will also provide generic domain model libraries for various types of application systems.

In the first phases of this project, the CONFIG 2 prototype has been developed and demonstrated. It integrates qualitative modeling, discrete event simulation, and digraph analysis technologies, and embeds them in easy-to-use software with interactive graphics for analyzing dynamic processing systems. The prototype supports evaluation of system diagnosability and fault tolerance, and supports analysis of the development—over time—of system effects of problems, including faults, failures, and procedural or environmental difficulties (fig. 1). It has been tested by modeling and analyzing effects of failures in a simple, two-phase thermal control system based on a Space Station prototype thermal bus, a reconfigurable computer network with various communications protocols, and the latching and deployment subsystems of the Space Shuttle remote manipulator system (SRMS). The positive results of these tests indicate the benefits to be gained from a reimplemented and enhanced system.

In the next phase of the project, CONFIG 3 is being implemented in the Common Lisp Object System (CLOS) language for rehosting onto Sun-class engineering workstations. (CONFIG 2 had been implemented using proprietary intelligent system and discrete event simulation software.) CONFIG 3 will also contain initial versions of modeling enhancements to meet requirements identified by SRMS operations personnel: hierarchical models, functional models, and procedure representation. Requirements and design for these capabilities have been developed this year. The CLOS language has been enhanced to support the object representation requirements of CONFIG models. CONFIG 4 will include analysis enhancements to support verification, validation, and updating of failure modes and effects analyses, fault management expert systems, and operations procedures.

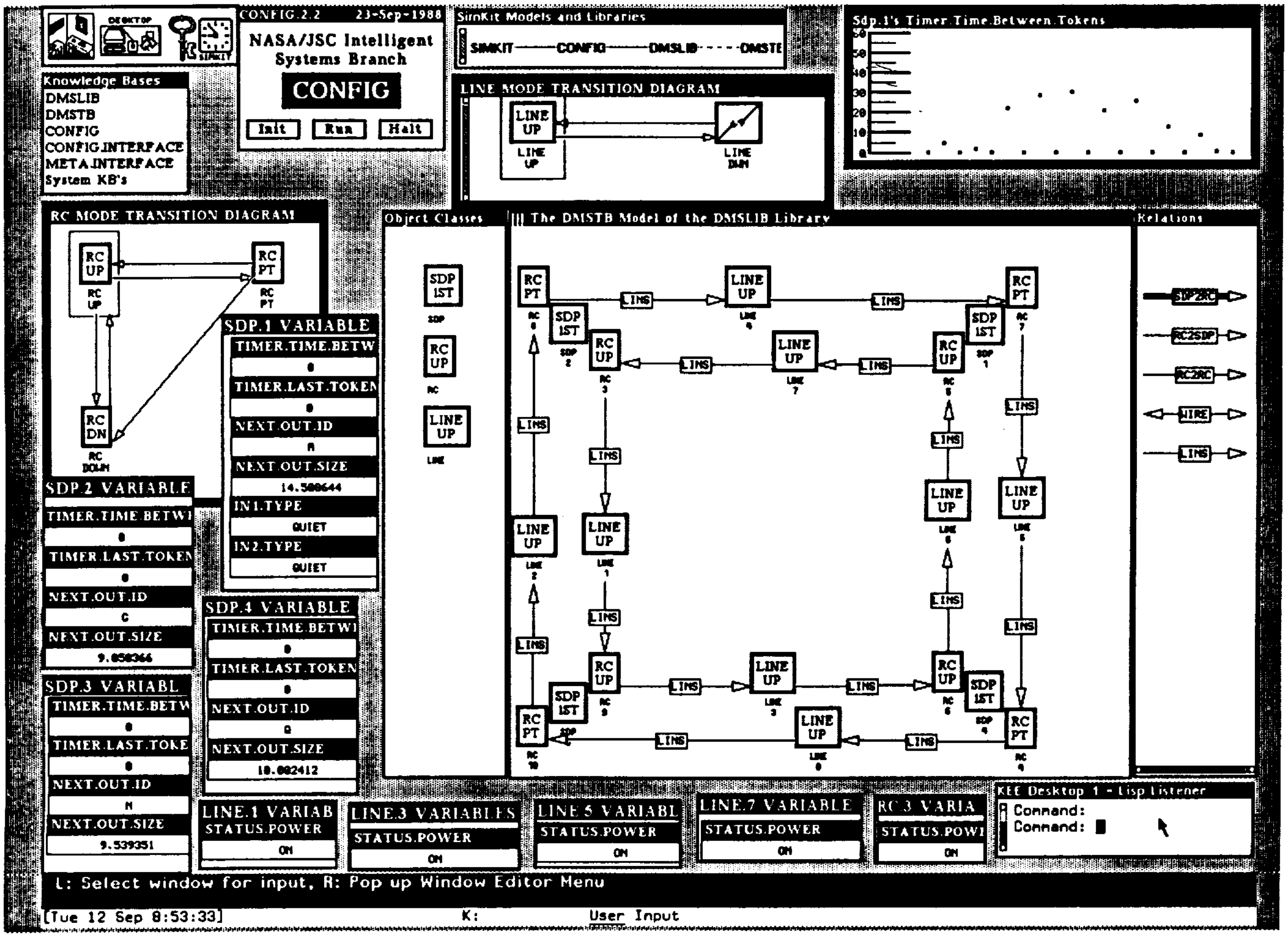

Figure 1. CONFIG screen: analysis of failure effects in reconfigurable computer networks.

Mission Evaluation Room Intelligent Diagnostic and Analysis System

PI: G. L. Pack/ER221
Reference: STT 3

The goal of the Mission Evaluation Room (MER) Intelligent Diagnostic and Analysis System project is to provide advanced automation software tools to engineers who must provide support to the MER during Shuttle flights. Intelligent software is designed and constructed to accomplish automated monitoring and analysis of telemetry data received from Orbiter systems. These tools help to alleviate the tedium and errors associated with routine data monitoring, accomplish "smart" logging of data under certain conditions, and provide assistance with the analysis of telemetry data. Applications have been introduced for the subsystems of the communications and tracking (C&T) system and the remote manipulator system (RMS).

This effort was combined with the efforts of the Flight Data Evaluation Office in an attempt to produce an integrated set of tools and associated data for MER engineers, called the MER Automated Toolset for Engineering Systems.

The C&T system was supplied with software to automatically monitor and log changes in discrete parameters for the S-band communications system (fig. 1), the test and graphics systems, and the payload communications system. These software applications continuously monitor the discrete parameters and collect information regarding their status. Additionally, a set of critical parameters is continuously monitored and displayed in numerical form. The software provides a facility to allow the user to annotate the information in the log with either a "canned" comment or a user-supplied comment.

The C&T applications that were originally coded in a vendor-specific graphics format have been converted to the highly portable X-Windows environment.

A similar effort was initiated for the RMS. During FY91, existing software was installed for use and evaluation by RMS engineers during Shuttle flight STS-48. Currently, software is being constructed to monitor the direct drive test (DDT) of the RMS joint motors. The DDT monitor will automatically detect the initiation of the DDT and plot the results on a screen as the test occurs. The plotted data can be overlaid on a historical template of DDT data for comparison of current behavior to past behavior. Completion and installation of this module is scheduled for the next RMS flight, STS-49, in April 1992.

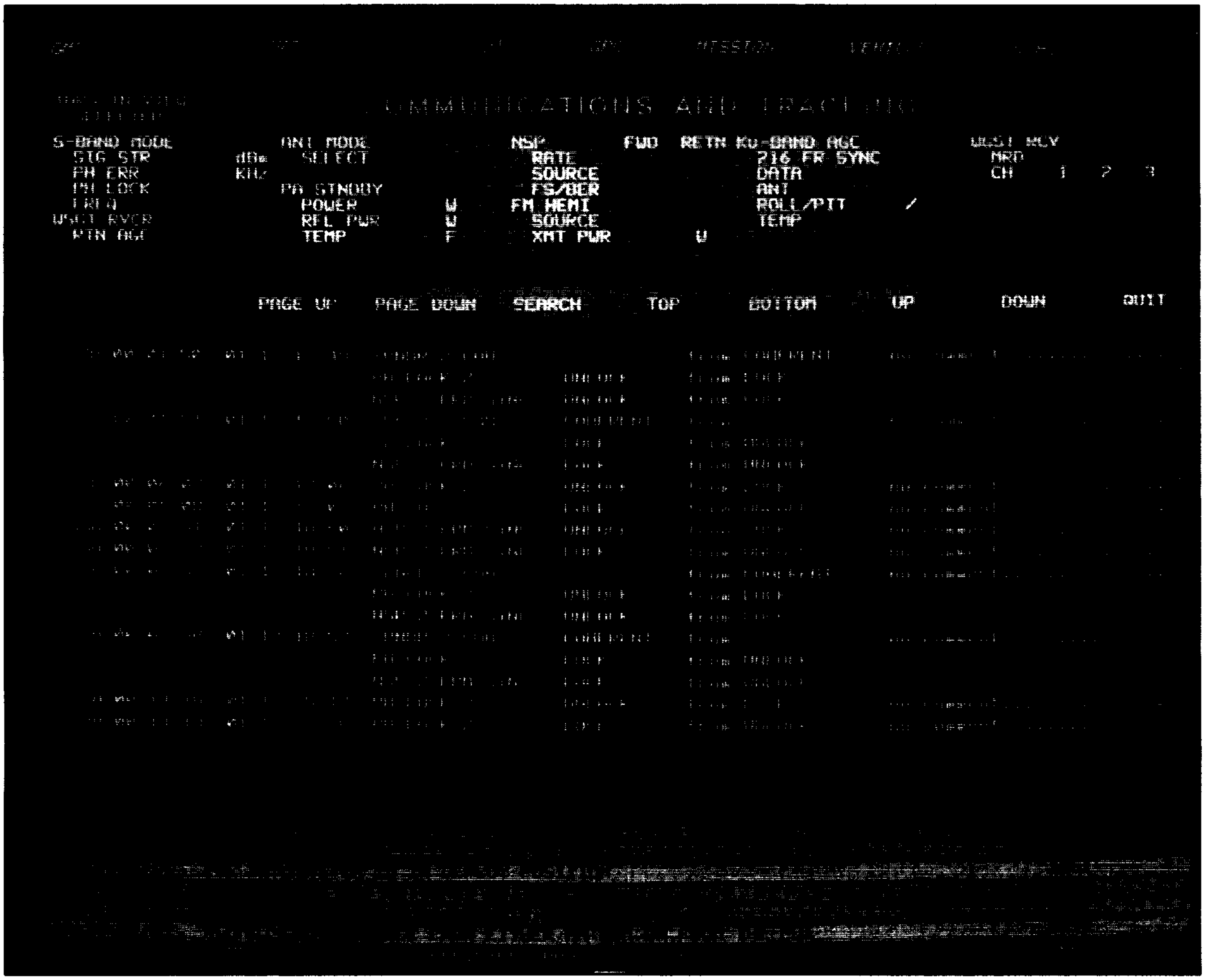

Figure 1. Orbiter S-band antenna system automated discrete monitor and logging screen.

Telepresence Workstation Development

PI: Michael J. Stagnaro/ER43
Reference: STT 4

Teleoperated robots require one or more humans to control actuators, mechanisms, and other robot equipment given feedback from onboard sensors. To accomplish this task, some form of control station is required. Desirable features of such a control station include operation by a single human, comfort, and natural human interfaces (visual, audio, tactile, etc.). These should work to maximize performance of the human/robot system.

The current task is to develop a breadboard test-bed of the control workstation described above. This breadboard is to be evaluated with two teleoperated robots. Features of the robots include anthropomorphic mechanisms, slaving to the control station, and delivery of sensory feedback to the control workstation. The breadboard will make use of technologies such as helmet-mounted displays and exoskeleton arm masters. A conceptional architectural representation of the telepresence workstation is shown in figure 1. A work breakdown structure of this task reflects five major milestones.

- Implement basic functions of the Johnny 5 robotic mechanism.
- Develop the breadboard workstation.
- Integrate and evaluate the workstation with the Johnny 5.
- Integrate and evaluate the workstation with the dexterous anthropomorphic robotic test-bed (DART).
- Develop a plan for the next phase of workstation development.

The Johnny 5 robotic mechanism of the movie "Short Circuit" has been selected as the initial slave robot. It was designed for teleoperation that required up to four humans with commercial radio control transmitter hardware. The workstation will allow one human to control all major functions of this slave robot. Basic functions of the Johnny 5 are currently being implemented.

The DART will also be interfaced with and controlled from the workstation. DART represents a much more robust and intelligent system when compared to the Johnny 5, although the hardware is currently in development. The schedules and work breakdown structures of both DART and this project have been coordinated so that the workstation task produces a product needed by DART.

A basic concept of the workstation has been developed. The key components and technologies are currently under study in preparation for the design phase. Design will be followed with fabrication of the breadboard and interfacing with the robots. Successful interfaces will then allow evaluations to proceed and planning to begin.

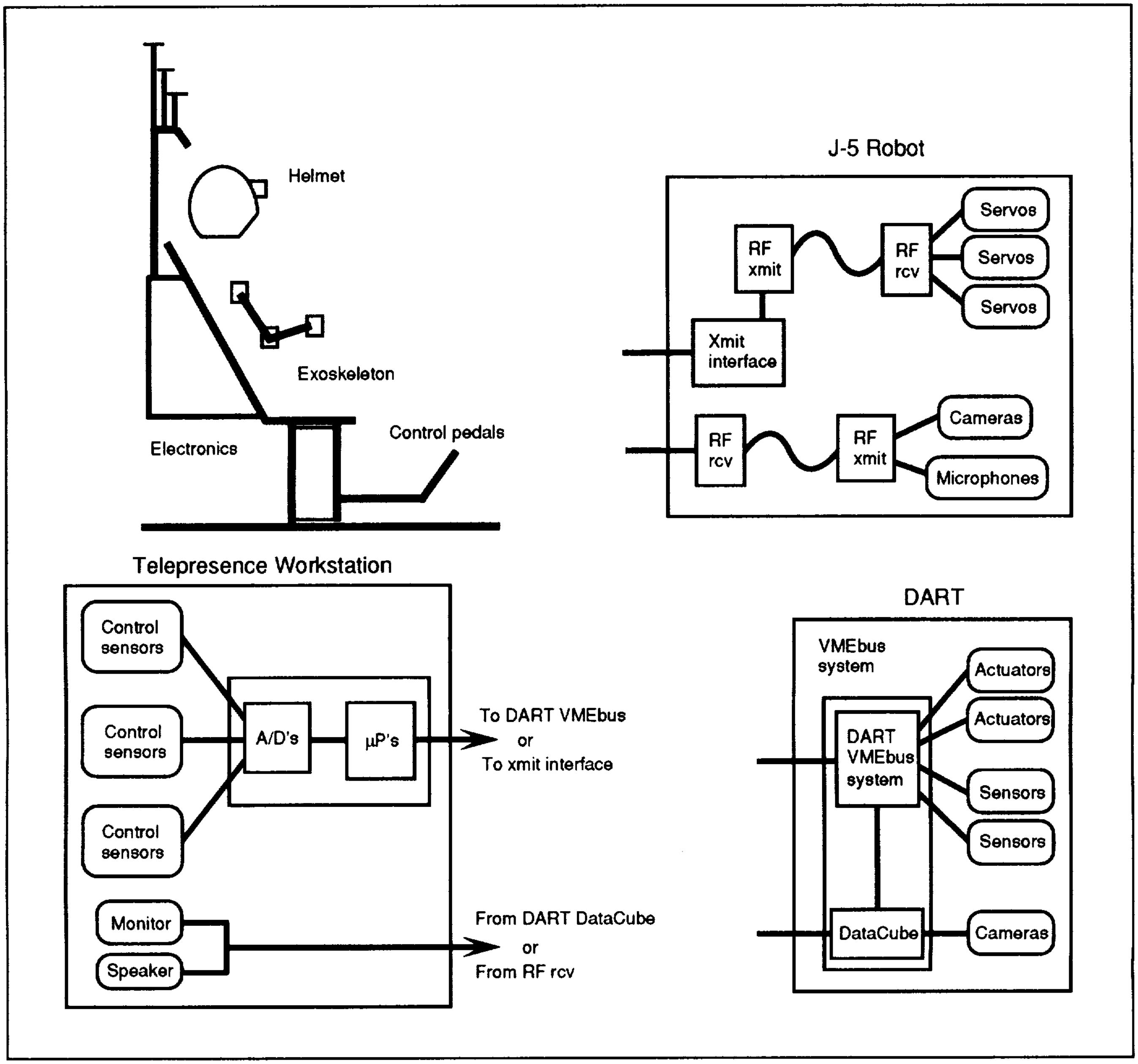

Figure 1. Telepresence workstation architecture concept.

Advanced Avionics Architecture (Development Pathways)

PI: **Don C. Brown/EG1**
Reference: **STT 5**

A networked quality function deployment (QFD) technology demonstration was initiated. The results of the QFD will be used to initiate a cooperative process for continual evolution of an integrated, time-phased space avionics plan, including requirements and technology initiatives for NASA space missions. The plan will provide guidance for technology investment and establish synergism with aircraft and spacecraft projects and with the overall support infrastructure.

The demonstration involves data and voice conferencing nodes at the NASA/Johnson Space Center, Marshall Space Flight Center, Lewis Research Center, Langley Research Center, Ames Research Center, and Kennedy Space Center with a master node at Martin Marietta, Denver, which is facilitating the sessions. QFD spreadsheets and graphics are distributed in near real time to each participant on the network. Scoring of QFD elements and correlation of technology alternatives are worked primarily off-net between sessions. The sessions are used to review results and discuss issues.

It is believed that the QFD approach will make the expertise of key technical managers more accessible, traditional QFD meetings more productive, and will maintain continuity and momentum between meetings (fig. 1).

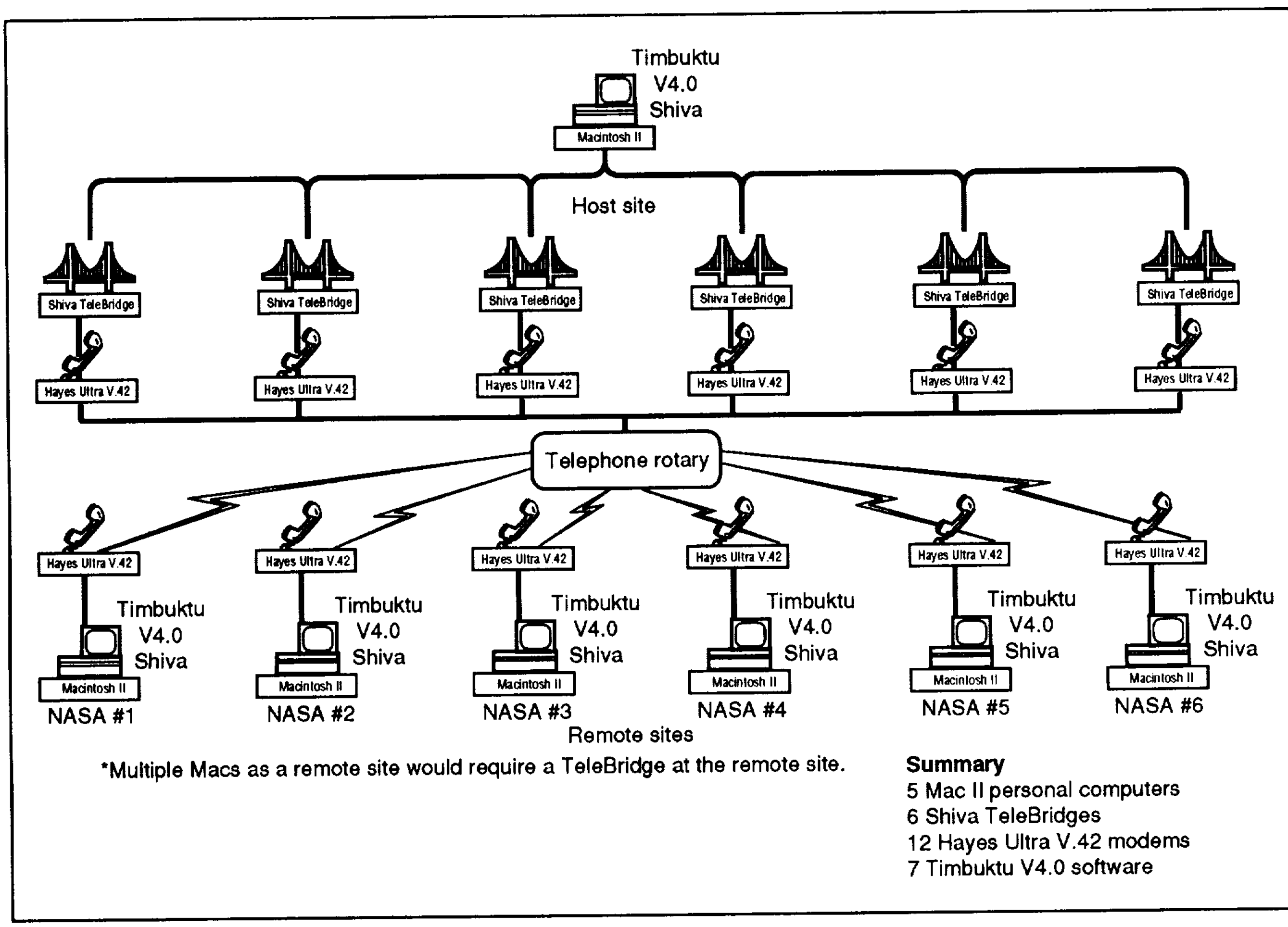

Figure 1. SATWG QFD computer network.

Autonomous Rendezvous and Docking Ground Demonstration

PI: **Steve Lamkin/EG431**
Reference: **STT 6**

The Exploration Program Autonomous Rendezvous and Docking Project completed approved work by conducting a ground demonstration of the current capabilities of guidance, navigation, and control software, sensors, and docking mechanisms to automatically complete the docking phase of a rendezvous and capture (fig. 1). The demonstration team, consisting of personnel from NASA/Johnson Space Center Navigation Control and Aeronautics Division, Tracking and Communications Division (EE), Structures and Mechanics Division (ES), and Automation and Robotics Division (ER) modified existing software for use in the test facility computers. A previously characterized laser sensor was provided by EE and mounted on the ES/ER Dynamic Docking Test Facility. An integrated test scenario was developed and prepared for implementation. Originally scheduled in November, the demonstration has been delayed because of facility constraints until February 1992.

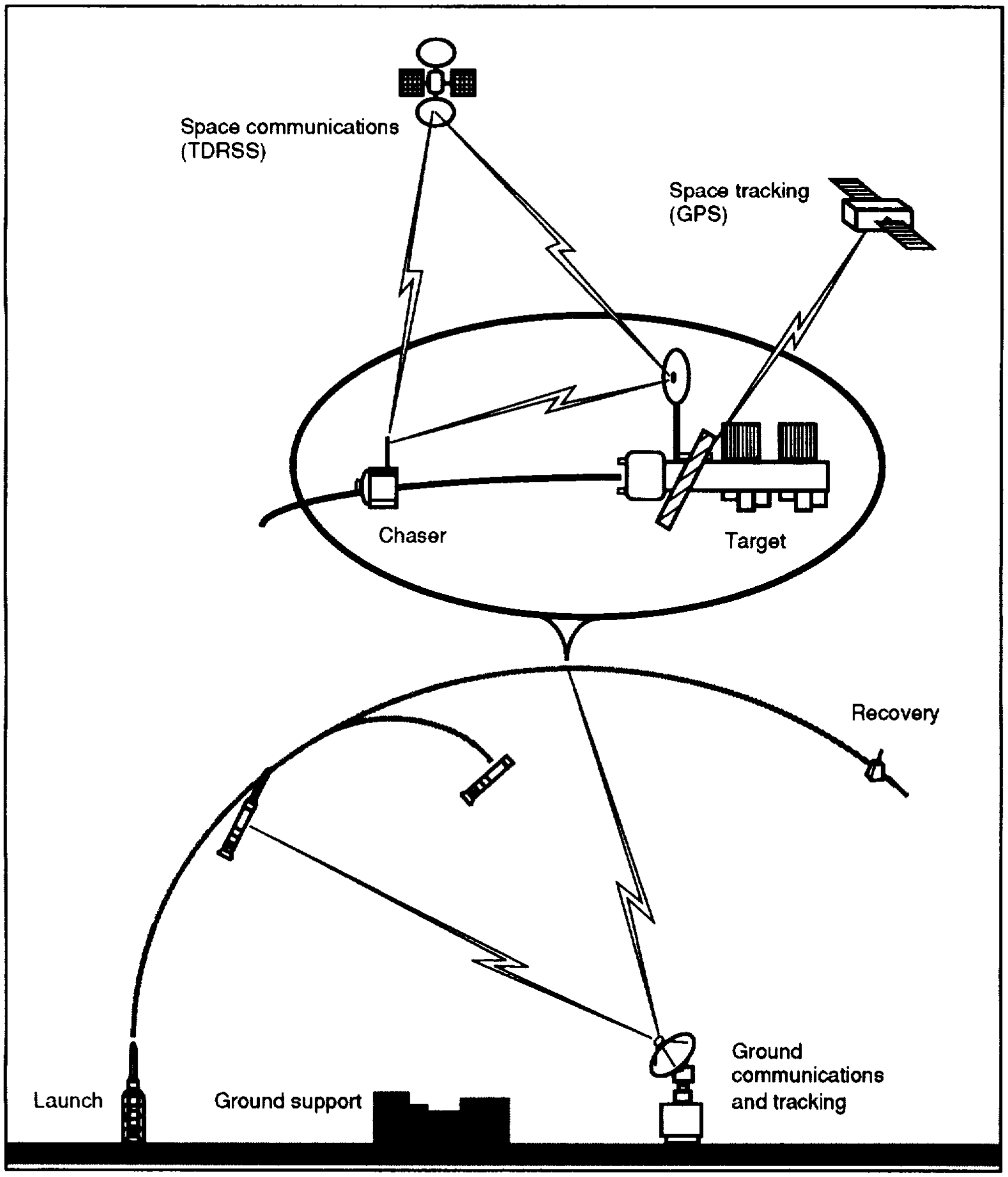

Figure 1. Typical rendezvous, proximity operations, and capture scenario mission.

Rendezvous, Proximity Operations, and Capture Quality Function Deployment

PI: **Steve Lamkin/EG431**
Reference: **STT 7**

A team consisting of NASA/Johnson Space Center Navigation Control and Aeronautics Division, Systems Engineering Division, Tracking and Communications Division, and Flight Design and Dynamics Division, Lockheed Engineering and Sciences Co.-Houston, TRW, Charles Stark Draper Laboratories, McDonnell Douglas Space Systems Co.-Houston, Martin Marietta-Denver, and General Dynamics Spacecraft Software Division personnel was formed in late March to perform a quality function deployment (QFD) on Remote Payload Operations Center (RPOC) technology. The team was sequestered off-site with full management support for 8 weeks. The team determined that the objectives of the RPOC QFD process would be to (1) identify the activities the RPOC community must accomplish over the next 3 years to satisfy the needs of their customers, and (2) determine how the RPOC leadership will meet customer needs. Ambiguous terms were defined; potential customers of RPOC technology and support were identified; and a hierarchy of customer needs was established.

Selected customers were interviewed to determine accurately their RPOC support requirements. From the hierarchy of customer needs, a list of potential solutions to satisfy those needs was formulated (fig. 1). The list was then examined to determine relationships between potential solutions and customer needs. Finally, the relationships between customer needs and potential solutions were evaluated and weighed to determine those activities that should be pursued by the RPOC community.

The commitment by management of sufficient time for the QFD process freed team members from pressure to "get the job done quickly" and permitted true consensus in areas of mixed understanding. Customer enthusiasm was high in working with the team to ascertain RPOC needs. A report on the RPOC QFD process and the results was written and published as document number JSC-25458.

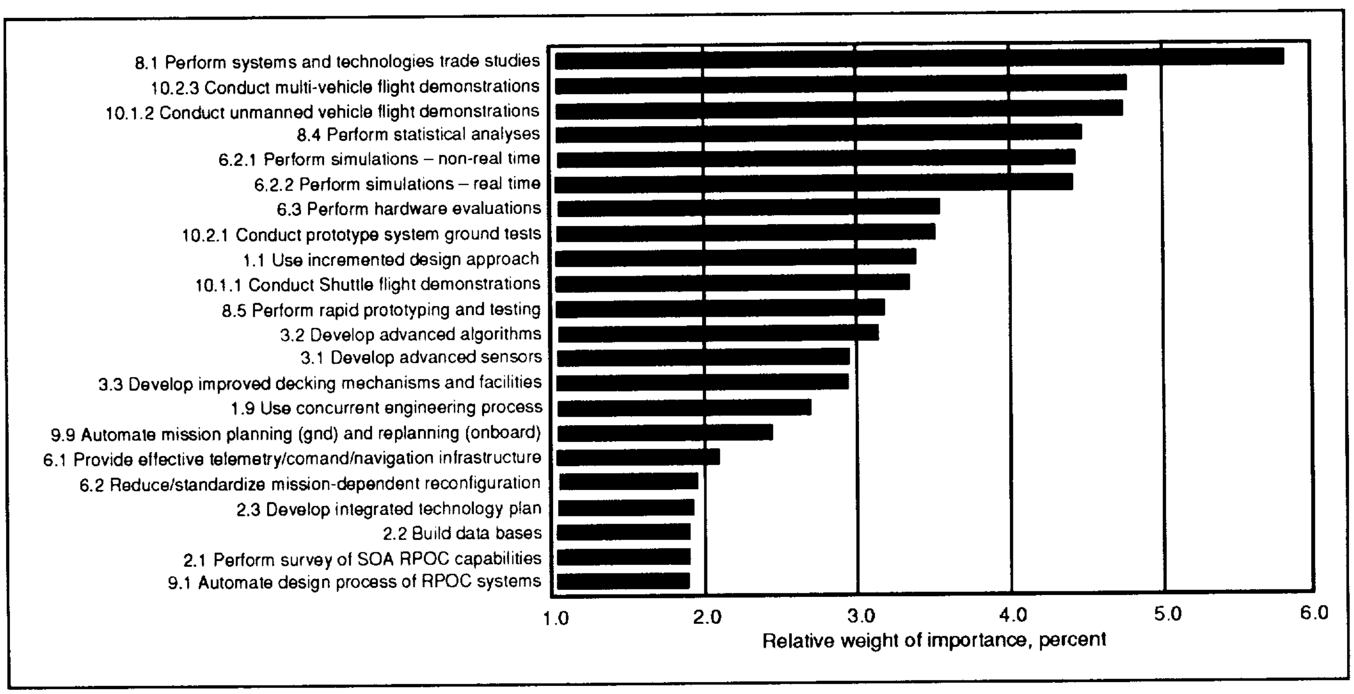

Figure 1. Ranking of technical solutions to customer needs.

Extravehicular Maneuvering Unit Electronic Cuff Checklist

PI: **Jose Marmolejo/EC6**
Reference: **STT 8**

This in-house activity with Lockheed Engineering and Sciences Company (and Lockheed Missile via Form 100) is for the design, development, and testing of an enhanced extravehicular maneuvering unit electronic cuff checklist. Since extravehicular activity (EVA) missions have grown in complexity, the amount of information required by the EVA astronaut has grown. The goal of this project is to demonstrate that an electronic cuff checklist could replace the need for the current paper procedural checklist. The current paper cuff checklist is limited to 25 pages (50 pages including front and back) that are cumbersome to use, time-consuming to assemble, and rarely up-to-date with current training procedures due to difficult configuration management control. On the other hand, the electronic cuff checklist under development (fig. 1) is expected to improve astronaut EVA productivity by providing a portable information display system that will allow the crewmember to have ready access to a much larger data base. The electronic cuff checklist information display will be worn over the space suit arm assembly (as is the current paper cuff checklist) to provide easy access to text and graphics data bases (of greater than 500 pages) via a digital display and three toggle switches. This data base is both reprogrammable and expandable via a serial data port to accommodate the data requirements of various Shuttle EVA mission tasks. In addition, training should be improved since the astronaut can be provided with earlier access to the latest data bases. A "hypercard" training tool is being developed to allow the astronaut the opportunity to participate in the "design" of the contents of the unit data base. The hypercard training tool also allows efficient loading of the data base, since captured images can be inserted directly into the electronic cuff checklist. The additional benefit of better configuration management control will be achieved by utilizing an access-controllable electronic data base.

Current year activities include the development and crew test of a functional prototype. This battery-powered unit includes an off-the-shelf electroluminescent display, driver electronics, memory, serial data programming port, and three 3-position toggle switches. Access to the memory contents is accomplished via a unique "sextant" screen protocol. Accomplishments include numerous engineering design trades with valuable inputs provided from the Crew, Man-Systems Division (Human-Computer Interface), Mission Operations (Flight Data File and EVA Crew Systems), and Crew and Thermal Systems Division (EVA Branch) personnel.

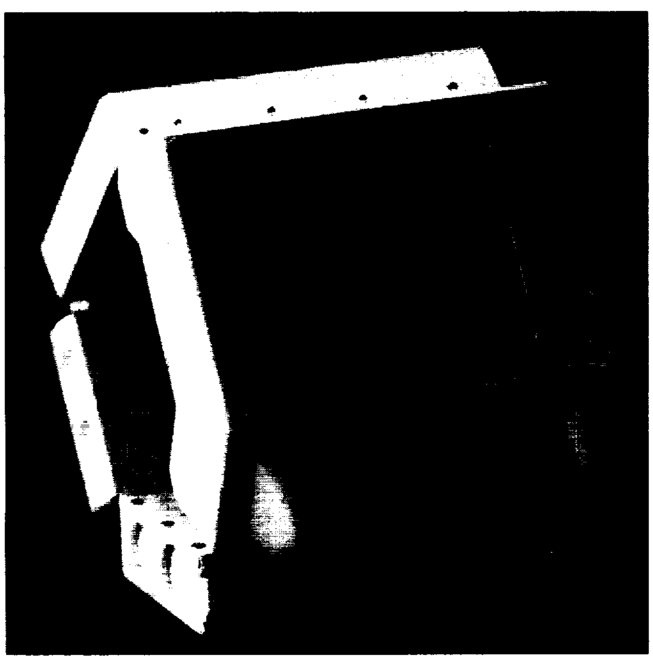

Figure 1. Electronic cuff checklist.

Shuttle Remote Manipulator System Advanced Force/Torque Control

PI: **Donald A. Barron/ER3**
Reference: **STT 9**

The objective of the Shuttle remote manipulator system (SRMS) advanced force/torque (F/T) task is to provide a demonstrated capability to use force/torque sensing at the SRMS end effector to improve control and to influence definition of the SRMS future upgrades. Closed-loop force control provides automatic accommodation of contact forces between the Shuttle arm and other external structures. It can be applied to increasingly complex future Shuttle missions to reduce risk and enhance performance. Force feedback control techniques developed for the SRMS can be applicable to other remote manipulator systems and servicers for Space Station as well.

The task is divided into three phases. It began in FY89 and ended in FY91. The first phase (FY89) investigated and applied candidate control laws to an industrial robot arm. A mockup of a payload berthing task was used to demonstrate the effectiveness of a closed-loop force feedback control as compared to an open-loop mode. Two reports were published in this period. The second phase (FY90) tested the candidate control laws using a non-real-time simulation of the SRMS (MIRRORS). SRMS nonlinearities that influence the stability and performance of a candidate control law were also identified via this non-real-time simulation. Experiments were performed and demonstrated in the Manipulator Development Facility where the contact forces were controlled, while the manipulator performed constrained motion tasks such as: pushing on a plate, tracing a V-guide surface, and inserting a square peg in a hole (0.06 in. clearance).

During FY91, the effects of the SRMS servo nonlinearities (i.e. gearbox backlash, friction, actuator drive limits, and integrator saturation) on the stability limits, and performance of a candidate force control law were analyzed using describing function approaches. Force feedback compensators were designed and tested for a single-link SRMS model (unloaded/loaded) and a full 6-degree-of-freedom SRMS non-real-time simulation (unloaded/loaded). A demonstration of F/T control was performed in the Dynamic Docking Test Facility (DDTF) (fig. 1). The docking forces between a simulated Shuttle and Space Station were controlled while the SRMS grappled the Station and pulled it inside the Shuttle bay for docking using DDTF docking port hardware. A paper was published to summarize the analytical and experimental results during this period. A final report is being prepared.

The results from this study can be summarized as follows: ground-based experimental results indicated that, for a given arm configuration—with known environment—dynamic characteristics and a SRMS-based simulator with arm dynamics assumed to be known, an endpoint force feedback compensator can be designed such that the arm will interact with its environment in a stable manner. Due to the limited bandwidth imposed by the structural flexibilities and a low sampling rate (12.5 Hz) available on board the Shuttle, high-frequency contact forces—such as occur at impact—cannot be actively controlled using any force feedback control scheme. Fortunately, controlling the impact force can be, and has been, done numerous times in past Shuttle missions by approaching contact at a very slow speed. Controlling the contact forces at steady state is definitely within the capabilities of the tested control laws in a simulated environment. A future task could be a flight experiment where a specific task could be fabricated to provide a controlled test environment for testing a candidate control law. Data from this flight test would be one of the essentials in deciding the worthiness of F/T-controlled SRMS.

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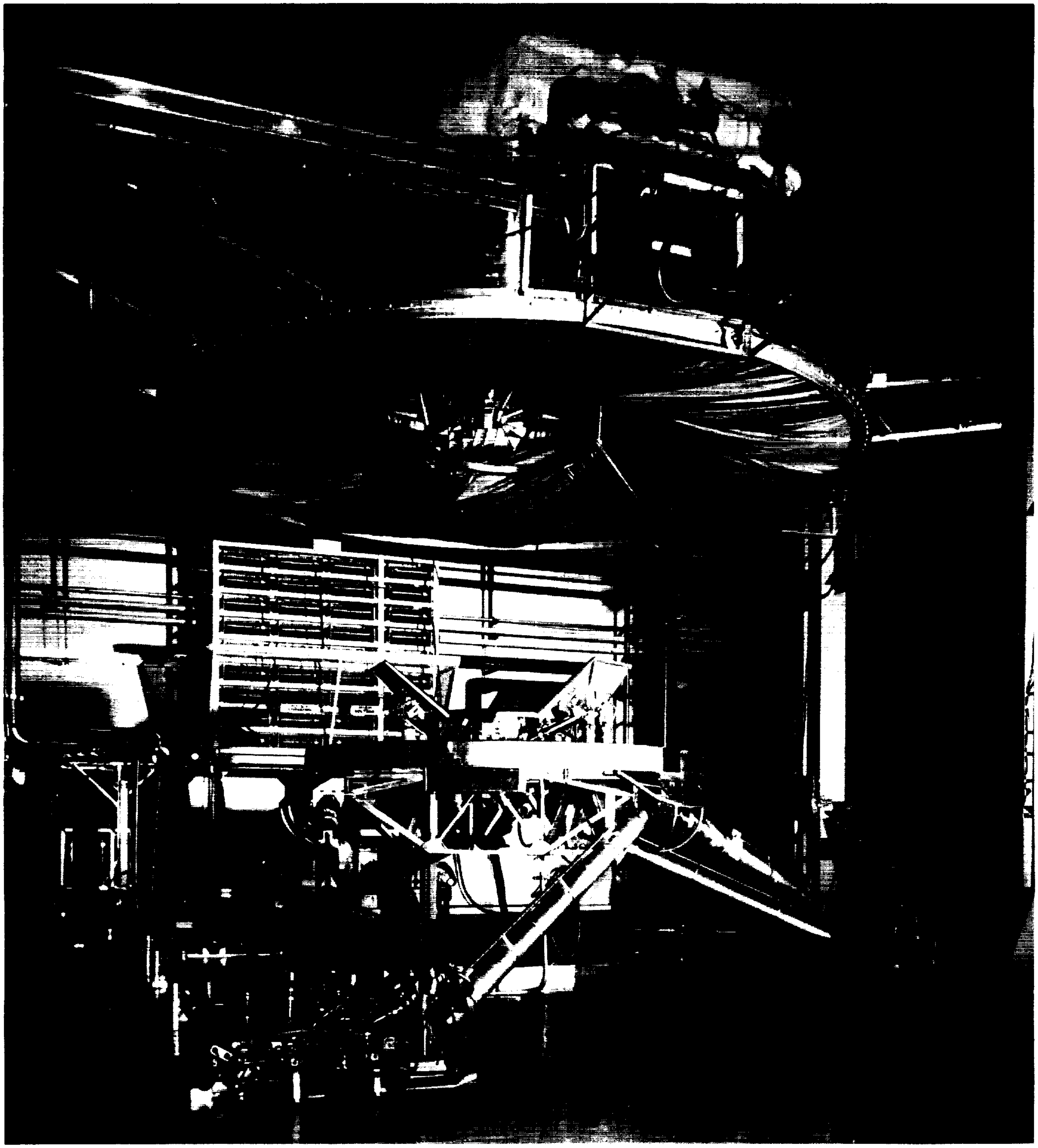

Figure 1. 6 degree-of-freedom table.

Rocket Research Long-Life Hydrazine Thruster Program

PI: **Christopher G. Popp/EP4**
Reference: **STT 10**

The Space Station Freedom (SSF) propulsion system uses an anhydrous hydrazine system that requires an extension of the impulse life capability of the catalyst-based thrusters. As part of the NASA supporting development activity for SSF, an evaluation program of potential long-life hydrazine thruster designs was continued from FY90. During that period, contracts had been established with three manufacturers, Marquardt, Hamilton Standard, and Rocket Research, to produce a modified off-the-shelf 50-lb class hydrazine thruster capable of achieving an impulse life of 2M lb-sec or approximately twice that demonstrated by existing hydrazine thrusters of similar thrust levels.

In early FY91, a thruster was designed, manufactured, acceptance tested, and delivered by Rocket Research. During the acceptance testing of this unit, the measured specific impulse and thrust performance at a 300 psia supply pressure were 234 sec 57 lbs, respectively. This thruster was then tested at the Thermochemical Test Area of NASA/Johnson Space Center to identify thruster life and performance under operating conditions similar to those projected for on-orbit SSF propulsion system operation. The unit was subjected to three simulated Shuttle payload launch vibration environments followed by extended thruster firings at a 100,000-ft. simulated altitude minimum to an accumulated impulse life of over 1.0 million lb_F-sec. Because of facility propellant storage limitations, test sequences were limited in duration to approximately 190,000 lb-sec of accumulated impulse (838 lbs of hydrazine throughput) maximum. Testing was performed with monopropellant grade hydrazine, which has been selected for use on the SSF propulsion system, to evaluate the designs for known performance anomalies associated with this hydrazine grade.

The Rocket Research thruster performed satisfactorily to an accumulated impulse of 1,100,000 lb/sec in the initial test phase. Chamber pressure roughness was ±8% peak-to-peak (or at the level observed in acceptance testing). During the course of this test program, Rocket Research and, ultimately, this design were selected for the SSF thrusters; as a result, additional testing was conducted on this thruster to accumulate an impulse life of 3,250,000 lb/sec. Chamber pressure roughness at the termination of the program was ±18% peak-to-peak. The Rocket Research thruster is shown in figure 1 on the following page after 45 sec of operation. Although the performance of the Rocket Research thruster was excellent during this program, a minor and a major performance anomaly were observed during the test. The minor anomaly consisted of an intermittent pressure spiking during the tail-off of the chamber pressure after a firing had been terminated. This occurred only on short-duration pulses (100 ms on) following long-duration firings (on the order of 1 to 2 hr), and is believed to be related to high temperatures in the injection system and/or "cooking off" of accumulated liquid propellant within the thruster. The second and more major performance anomaly was the intermittent appearance of a hot white spot at several locations on the outer pressure chamber wall on the injector end of the thruster accompanied by significant localized injector and catalyst bed temperature variations. Disassembly and inspection of the thruster at Rocket Research found cracks in the bed forward heat shield and injector caused by low-cycle thermal fatigue and creep rupture under operating conditions. Additionally, higher-than-expected operating temperatures (as evidenced by the operational temperatures and piece part surface melting found during inspection) may have contributed to these failures. These findings are being used to aid the SSF thruster design process.

Primary Reaction Control System Thruster Metallic Nitrate Flushing

PI: John Albright/EP4
Reference: STT 11

The Space Shuttle primary reaction control system (PRCS) thruster is a pressure-fed engine utilizing hypergolic propellants, monomethylhydrazine, and nitrogen tetroxide (NTO) to perform vehicle attitude control while on orbit and during reentry. Due to a series of thruster in-flight failures and NTO ground leaks since STS-26, an investigation of metallic nitrate contamination and potential removal techniques was initiated.

Metallic nitrate, primarily nickel-, iron-, and chromium-based, is a reddish-brown gelatinous substance generated as a result of reaction control system base metal attack from nitric acid. The nitric acid is a product of the reaction between NTO and water that is inherently present in flight-grade propellant and is also introduced into the system from the environment. These nitrates have been found consistently deposited throughout the pilot-operated oxidizer valve (fig. 1); they adversely affect mechanical performance and sealing capability.

The project objective was to develop a thruster-flushing procedure capable of removing contamination from flight thrusters, enabling their return to service without the cost and schedule impact of valve replacement at the manufacturer. The developed procedure includes a flush with deionized water (owing to its ease of use and high level of nitrate solubility), effluent monitoring and analysis, valve leakage and response checks, borescope inspection of injector flow, and a vacuum bake upon completion. Procedure development was accomplished by flushing discrepant Fleet Leader valves initially at the valve level (i.e., valve removed from the thruster body) and finally at the thruster level (i.e., valve attached to the thruster body). After sufficient demonstration, three flight thrusters were then flushed at the thruster level.

During flush development and demonstration at the White Sands Test Facility (WSTF), significant reductions in valve leak rate, increases in valve cleanliness, and a 50% rate of recovery with respect to all applicable valve specifications (i.e., leak rate, response, cleanliness, mass flow rate, and pull-in/hold-in voltage) have been achieved. As a result, efforts are under way to certify the flush procedure and WSTF facility as an interim repair depot for PRCS thrusters suspected of nitrate contamination. A reassessment of both the thruster failure and flushing success rates is also planned in the next year to evaluate the transfer of this capability to NASA/Kennedy Space Center.

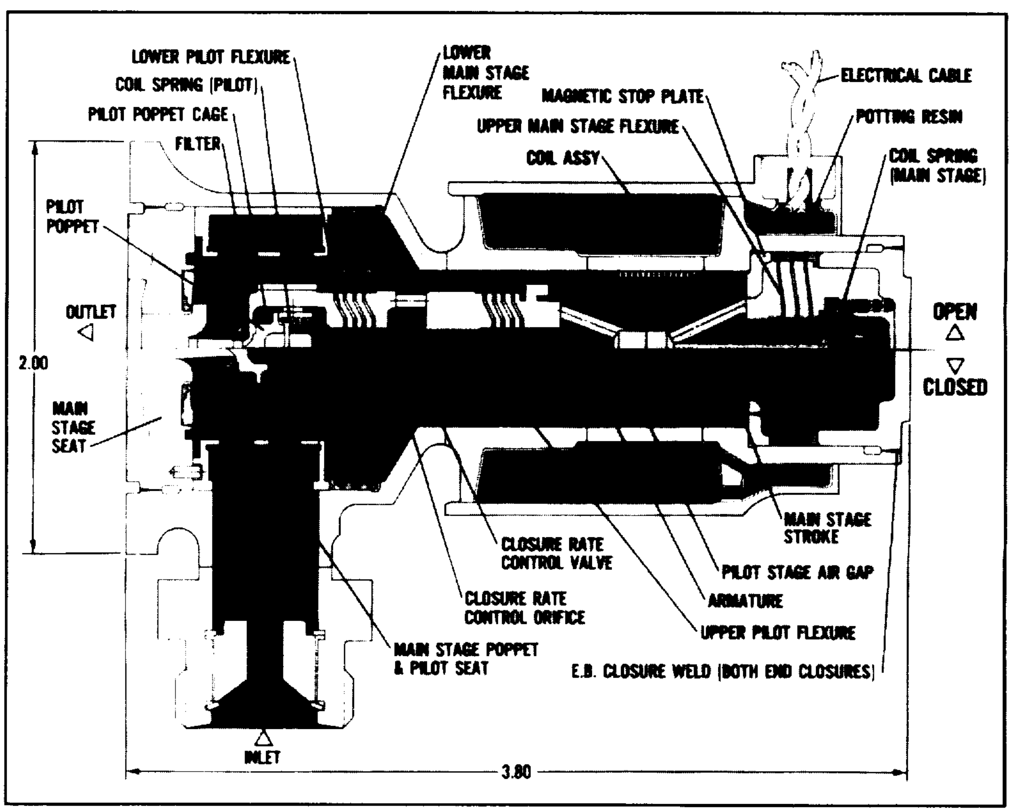

Figure 1. PRCS thruster pilot-operated valve.

Rocket Engine Combustion Stability

PI: **Eric Hurlbert/EP4**
Howard Flynn/EP4
Reference: **STT 12**

This task is an in-house effort to develop combustion stability analysis capability. The primary focus is on the Shuttle primary reaction control system (PRCS) thruster, for which vast amounts of test data are available, though little analytical understanding exists. The results of the White Sands Test Facility stability test program and the low thrust test program are being analyzed.

The tool for this analytical capability is the rocket combuster interactive design (ROCCID) computer program developed by Aerojet under a NASA/Lewis Research Center (LeRC) contract. ROCCID is a compilation of the best existing verified computer models used in industry and government (ODE, LEINJ, etc.). ROCCID acts as a shell to integrate these programs to evaluate the responses and damping of the engine elements and to output the stability of the design. Figure 1 below shows some of the parameters entered into ROCCID.

Funding was transferred to LeRC for inclusion of MMH/N_2O_4 and unlike doublets in the ROCCID model to analyze the PRCS thruster. This computer model has been installed on the PPD VAX computer. Currently, runs are being made using Taguchi methods to understand the effects and interactions of the thruster parameters on the chug stability of the thruster.

The Joint Army Navy NASA Air Force Combustion conference was attended. The Propulsion Branch will participate on two committees as a result of the conference; (1) to revise the CPIA Publication 247 Guideline for Combustion Stability Specifications and Verification Procedures, and (2) to create guidelines for research of combustion stability that specify useful test conditions, simulants, injectors, etc.

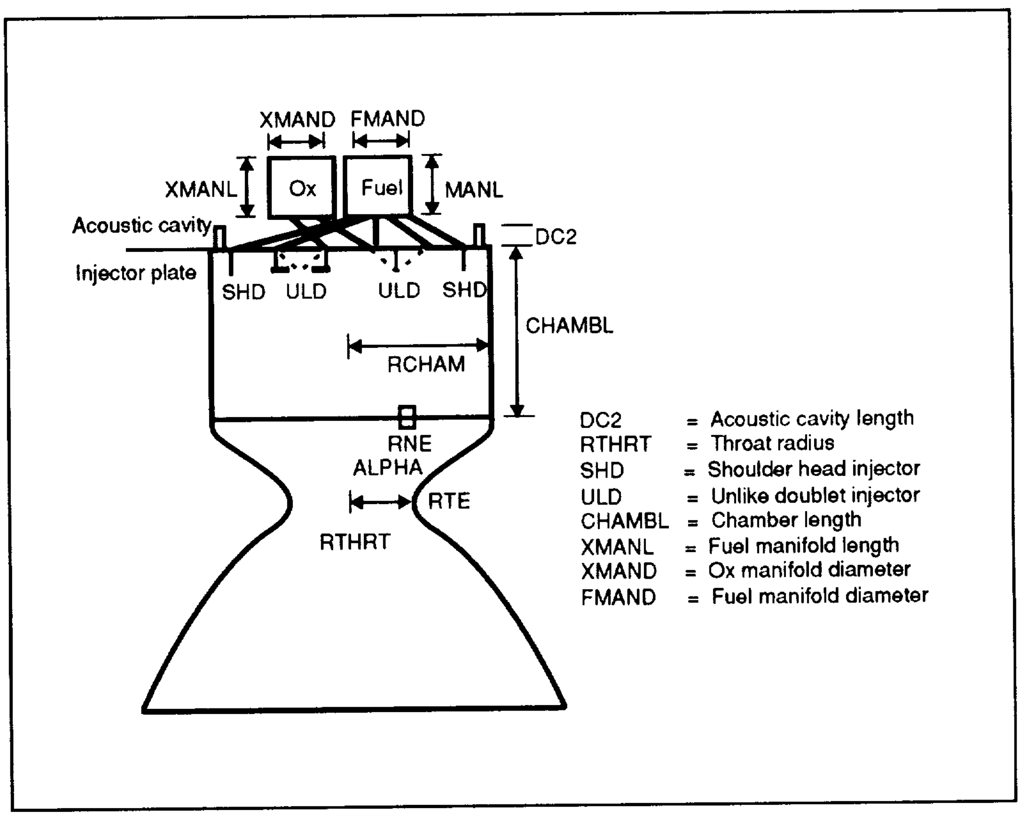

Figure 1. Engine parameters used in combustion stability model.

Aeroassist Flight Experiment

PI: **Donald Curry/ES**
Vuong Pham/ES
Carlos Ortiz/ES
Christopher Madden/ES
James Milhoan/ES
Robert Maraia/ES

Reference: **STT 13**

The aeroassist flight experiment (AFE) is a multi-center, Agency-sponsored technology enhancement experiment with overall project management at NASA/Marshall Space Flight Center. The Thermal Branch continued to provide project management for the AFE functions located at the NASA/Johnson Space Center (JSC) that encompassed aerobrake design and fabrication, including science experiment integration; guidance and navigation support; aerobraking trajectory design and mission planning support; the aerodynamic performance experiment; the base flow and heating experiment (BFHE); aerobraking aerothermodynamic definition; aerobraking aerodynamic definition; and computational fluid dynamic analytical support.

During the past year, the JSC aerobrake activity remained on schedule and within budget. The structure and thermal protection system (TPS) design process were completed, and all design issues raised at the contract design review in FY90 were resolved successfully. All development testing involving the use of small components of the aerobrake structure and TPS was completed, and all results were within predicted ranges. The full-scale structural hardware for certification tests were completed, and preparations for the static structural test were initiated. All structural hardware for the flight aerobrake was prepared and placed in bonded storage. Approximately 50% of the flight TPS tile production was completed. Due to budget constraints, the AFE project was canceled October 1, 1991. An extensive in-house study has been made to develop costs and schedules commensurate with an in-house team approach for performing the AFE project as a JSC-managed effort.

BFHE boom thermal analysis: BFHE booms are used as a platform for instrumentation on the leeside of the AFE vehicle. An update to previous thermal analyses of the booms was completed to account for on-orbit effects. The analysis showed that the booms will survive the aeropass flight of the AFE, and all TPS components of the boom will remain intact and will perform as designed. The transient response predicted by the analysis for the leading boom is shown in figures 1 and 2. Notice that the surface temperature remains below 2900°F. and the room temperature volcanizing (RTV) bond remains below the limit of 625°F. The trailing boom experiences are a more benign environment, and the temperatures also remain within the material limits for all phases of the mission.

Aerobrake thermal assessment and heat load constraint: To ensure mission success, a 1-dimensional parametric thermal analysis was completed so that a maximum stagnation point heat load for the aerobrake could be determined. It is this maximum heat load that will be used for trajectory shaping along with the maximum heating rate. In figure 3, the maximum (over the entire aerobrake) RTV bond temperature peak is compared to the heat load at body point 100 for different trajectories. The maximum stagnation point heat load using this method is 8468 BTU/ft^2. The temperature limit for the RTV possibly would be increased to 675°F, and therefore the maximum heat load would be dependent upon the maximum peak structure temperature shown in figure 4. Therefore, if the RTV temperature limit were increased to 675°F, the maximum stagnation point heat load for the aerobrake would be 9880 BTU/ft^2.

On-orbit off-nominal aerobrake thermal analysis: A thermal analysis was performed to determine the effects of off-nominal worst hot (ZSI - Orbiter Z-axis solar inertial or top to Sun) and worst cold (Orbrate - Orbiter tail to Sun, top to space, spinning around its own X-axis at a rate of 1 rev per orbit) on-orbit attitude holds and their respective recovery periods for the aerobrake while it is inside the Orbiter payload bay. The recovery attitude is ZLV-XVV, or Orbiter Z-axis local vertical with its X-axis on velocity vector (top to Earth, nose to velocity vector). All attitudes were analyzed for a beta angle of 52° and an altitude of 160 n. mi.

For the off-nominal hot attitude, the aerobrake and attached science hardware can be flown indefinitely without any temperature constraint violations. For the off-nominal cold attitude, they can be flown for about 2.2 hr before a nonoperating temperature limit (–67°F) of the radiative heating experiment is reached. Because the aerobrake and attached science hardware can be flown indefinitely in the off-nominal hot attitude hold, no thermal recovery period (the time in the nominal recovery before the off-nominal attitude can be repeated) is needed. The recovery period for the off-nominal cold attitude hold is about 12 hr.

Baseline 5-A equilibrium heating rate reassessment: Because of the uncertainty in the catalytic efficiency data and calculations for the AFE aerobrake, a thermal analysis was performed to assess the aerobrake TPS performance, using catalytic efficiency of one (fully catalytic wall or equilibrium heating). One-dimensional transient thermal analysis was performed at four different body points (100, 103, 301, and 302) with three different trajectories (nominal, heat rate dispersed, and heat load dispersed). Consequently, violations resulted in the surface temperatures (exceeded 2900°F for LI-2200 and 2700°F for FRCI-12), and/or in the RTV (exceeded 650°F for RTV), and/or in the structures (exceeded 400°F for aluminum). Therefore, the aerobrake TPS will not perform adequately in the fully catalytic heating environment.

On-orbit recovery attitude definition: On-orbit heating rates were calculated for a number of ZLV attitudes with beta angels ranging from –52° to +52°. As a result, at high beta angles (–20° > ß +20°), ZLV-XVV attitude will generate uneven heating from the starboard side to the port side. This uneven heating will result in undesirable thermal gradients in the aerobrake structure. A recommendation was made at an AFE thermal panel meeting to change the baselined recovery attitude from ZLV-XVV to ZLV+YVV. The request was approved and later incorporated into the system.

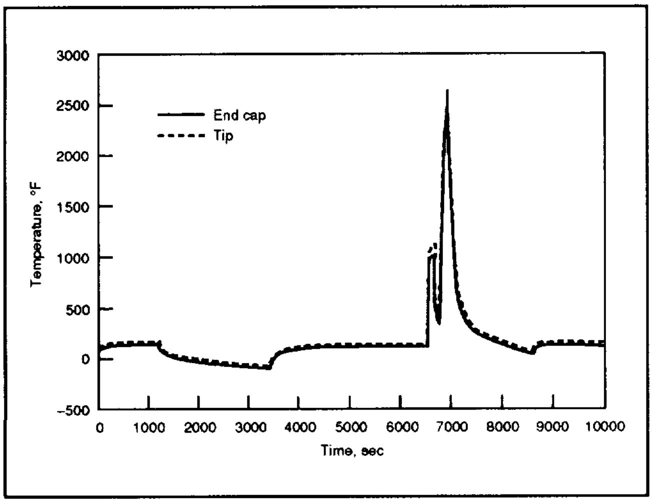

Figure 1. AFE BFHE leading boom: surface temperature history.

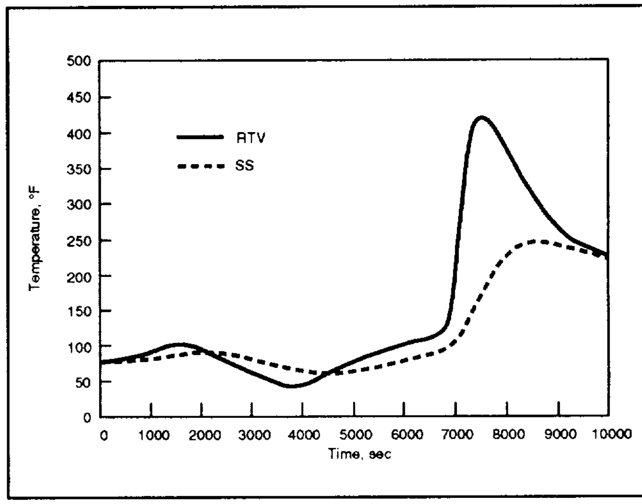

Figure 2. AFE BFHE leading boom: bond temperature history.

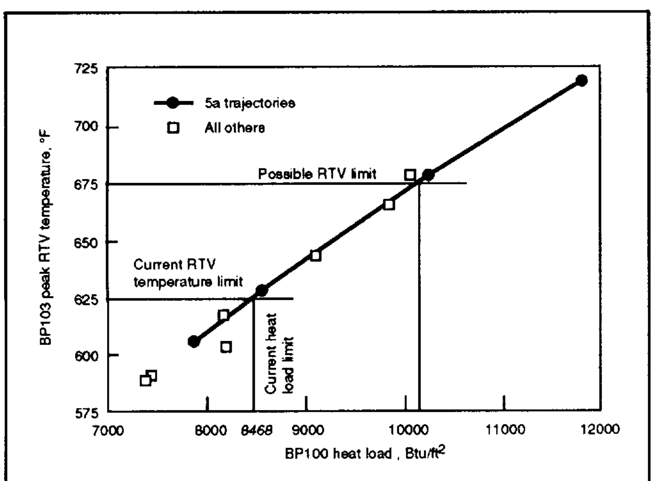

Figure 3. AFE aerobrake heat load 1-dimensional thermal analysis (bond temperature peak).

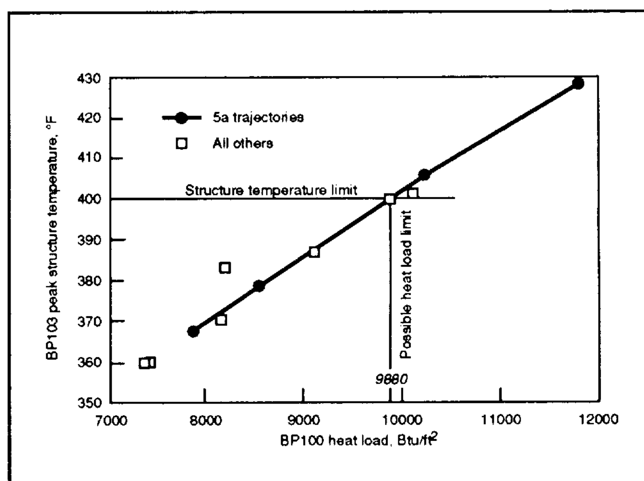

Figure 4. AFE aerobrake heat load 1-dimensional thermal analysis (maximum peak structure temperature).

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Reference Number

LIFE SCIENCES (LS)

LS 6 **B-Cell Radiosensitivity and Protection by Cytokines**

Funded by: Code 307-51-91-09
Technical Monitor: Clarence F. Sams, Ph.D./SD4/483-7160
Principal Investigator(s): David G. Ritchie, Ph.D./KRUG Life Sciences, Inc.; Peggy A. Whitson, Ph.D./SD4
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 7 **The Effect of Natriuretic Peptides on Prazosin Binding to Alpha1 Adrenergic Receptors in Mouse BC3H1 Cells**

Funded by: Code 199-18-11-15
Technical Monitor: Peggy A. Whitson, Ph.D./SD4/483-7046
Principal Investigator: W. Jon Williams, Ph.D./NRC
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 8 **Endothelial Cells Degrade Atrial Natriuretic Peptide**

Funded by: Code 199-18-11-15
Technical Monitor: C. F. Sams, Ph.D./SD4/483-7160
Principal Investigator(s): P. A. Whitson, Ph.D./SD4; S. J. Frost/NRC
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 9 **Blood Volume Responses of Men and Women During 13 Days of Bed Rest**

Funded by: Code 199-14-11-13
Principal Investigator: Suzanne M. Fortney, Ph.D./SD5/483-7213
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 10 **Cardiovascular Monitoring of Space Shuttle Astronauts During Return to Earth**

Funded by: Code S 106-70-0211
Technical Monitor: J. B. Charles, Ph.D./SD5/483-7224
Principal Investigator(s): M. M. Jones; K. A. Fuhrmann/KRUG Life Sciences, Inc.
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 11 **Noninvasive Cardiovascular Monitoring on Routine Space Shuttle Flights**

Funded by: Code S 106-70-0211
Technical Monitor: J. B. Charles, Ph.D./SD5/483-7224
Principal Investigator(s): M. M. Jones; M. A. Bowman/KRUG Life Sciences, Inc.; M .W. Bungo, M.D./SD5
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 12 **Electronic Vision-Occlusion Goggles for Performing Visual-Vestibular Integration Experiments**

Funded by: Code J24 NAS 9-18492
Technical Monitor: Millard F. Reschke, Ph.D./SD5/483-7210
Principal Investigator(s): Jacob J. Bloomberg, Ph.D.; William P. Huebner, Ph.D.; Deborah L. Harm, Ph.D. /SD5; William H. Paloski, Ph.D./KRUG Life Sciences, Inc.
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 13 **Stress-Assisted Nucleation: Its Role in the Etiology of Decompression Sickness in Microgravity**

Funded by: Code S 199-04-11-01
Technical Monitor: Michael R. Powell, Ph.D./SD5/483-5413
Principal Investigator(s): James Waligora/SD5; William Norfleet, M.D./SD5; Mark Davis/SD5
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 14 **A Statistical Model Describing the Incidence of Decompression Sickness and Doppler-Detectable Gas Bubbles During Altitude Decompression**

Funded by: Code S 199-04-11-01
Technical Monitor: James M. Waligora/SD5/483-7200
Principal Investigator(s): David J. Horrigan, Jr./SD5; John H. Gilbert, Ph.D./SD5; Johnny Conkin/SD5; John Stanford, Jr./KRUG Life Sciences, Inc.; Benjamin F. Edwards, Jr., Ph.D./SD5
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 15 **The Application of Integrated Knowledge-Based Systems for the Biomedical Risk Assessment Intelligent Network**

Funded by: Code S 107-20-02-01
Technical Monitor: Gerald R. Taylor, Ph.D./SD5/483-6057
Principal Investigator(s): Karin C. Loftin, Ph.D./KRUG Life Sciences, Inc.; Bebe Lye/PT4; Laurie Webster/ER2; James Verlander, Ph.D./SD5; Gerald R. Taylor, Ph.D./SD5; Gary Riley/PT4; Chris Culbert/PT4; Tina Holden, Ph.D./SP3; Marianne Rudisill, Ph.D./SP3
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc. NAS 9-18492

LS 16 **Concept Development of Preflight Blood Volume Reduction as a Countermeasure to Fluid Shifts in Spaceflight**

Funded by: Code NRC Fellow
Technical Monitor: John B. Charles, Ph.D./SD5/483-7224
Principal Investigator(s): Karl E. Simanonok, Ph.D./NRC; R. Srinivasan, Ph.D./KRUG
Task Performed by: Johnson Space Center
National Research Council
KRUG Life Sciences, Inc., NAS 9-18492

LS 17 **Prediction of Space Sickness**

Funded by: Code NRC Fellow
Technical Monitor: John B. Charles, Ph.D./SD5/483-7224
Principal Investigator(s): Karl E. Simanonok, Ph.D./NRC; Edward C. Moseley, Ph.D./SD
Task Performed by: Johnson Space Center
National Research Council
KRUG Life Sciences, Inc., NAS 9-18492

LS 18 **Evaluation of the LAMA RCH Hyperbaric Ventilator**

Funded by: Code M
Technical Monitor: Charles W. Lloyd, Pharm.D./SD2/483-7120
Principal Investigator(s): Michael Barratt, M.D./KRUG Life Sciences, Inc.; Linda Murphy/McDonnell Douglas Astronautics Corp.
Task Performed by: Johnson Space Center
KRUG Life Sciences, Inc., NAS 9-18492

LS 19 **Phase II Development of a Surgical Support System for Space Station Freedom—A Microgravity Animal Surgical Model**

Funded by:	Code M
Technical Monitor:	Roger D. Billica, M.D./SD2/483-7894
Principal Investigator(s):	Smith L. Johnston III, M.D./KRUG Life Sciences, Inc.; Mark R. Campbell, M.D./KRUG Life Sciences, Inc.
Task Performed by:	Johnson Space Center KRUG Life Sciences, Inc., NAS 9-18492

Reference Number	# HUMAN SUPPORT TECHNOLOGY (HST)

HST 1 — **Computational Human Factors: A Dynamic Human Strength Model**

Funded by:	RTOP 199-06
Principal Investigator(s):	Jim Maida/SP34
	Abhilash Pandya/LESC
	Ann Aldridge, Ph.D./LESC
	Barbara Woolford/SP34
	Scott Hasson, Ph.D./Texas Women's University
Task Performed by:	Johnson Space Center
	Lockheed Engineering & Sciences Co.
	Texas Women's University

HST 2 — **Prediction of Human Isolated Joint Strength from Lean Body Mass**

Funded by:	RTOP 506-71
Principal Investigator(s):	Jim Maida/SP34
	Abhilash Pandya/LESC
	Ann Aldridge, Ph.D./LESC
	Barbara Woolford/SP34
	Scott Hasson, Ph.D./Texas Women's University
Task Performed by:	Johnson Space Center
	Lockheed Engineering & Sciences Co.
	Texas Women's University

HST 3 — **Muscle Strength Measurements**

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Principal Investigator(s):	Glenn K. Klute/SP34
	Lauren Schafer/LESC
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HST 4 — **Computer Aided Tracking System**

Funded by:	Space Station Freedom
Principal Investigator:	L. W. Lew/SP33
Task Performed by:	Johnson Space Center
	Johnson Engineering Co.

HST 5 — **Weightless Environment Training Facility Diver Tracking System**

Funded by:	STS/SSF
Principal Investigator(s):	Leslie Schaschl/SP54
	Mike Cochran/Cochran Consulting, Inc.
Task Performed by:	Johnson Space Center
	Cochran Consulting, Inc.

HST 6 — **Crew Concept Maintenance Workstation**

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Principal Investigator(s):	Frances Mount/SP34
	Jason Beierle/LESC
Task Performed by:	Johnson Space Center
	Lockheed Engineering & Sciences Co.

HST 7 **Viewing Analysis for the Assembly of Space Station Freedom**

Funded by: SSF
Principal Investigator(s): Frances Mount/SP34
James Maida/SP34
Sheryl Stealey/LESC
Kim Tran/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 8 **Evaluation of Current Cupola Configuration on the Space Station Freedom**

Funded by: SSF
Principal Investigator(s): Frances Mount/SP34
James Maida/SP34
Sheryl Stealey/LESC
Lorraine Meagher/LESC
Kim Tran/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 9 **Extended Duration Orbiter Trash Compactor**

Funded by: EDO Project Office
Principal Investigator: J. B. Thomas/SP44
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 10 **Development of the Animal Enclosure Module**

Funded by: SSF
Principal Investigator: Neil Christie/SP33
Task Performed by: Johnson Space Center
General Dynamics

HST 11 **Shuttle Extended Duration Orbiter Beverage Package**

Funded by: STS
Principal Investigator(s): Charles T. Bourland, Ph.D./SP44
Vickie L. Kloeris/SP44
Michael F. Fohey/LESC
John F. Marcucci/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 12 **Head Tracking Versus Manual Input for Camera Control**

Funded by: STS
Technical Monitor: A. Jay Legendre/SP34
Principal Investigator(s): Meera K. Manahan/LESC
Ellen Hwang/LESC
John M. Bierschwale/LESC
Mark A. Stuart, Ph.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 13 **Multiple Remote Systems**
Funded by: RTOP 506-71
Technical Monitor: A. Jay Legendre/SP34
Principal Investigator(s): Mark A. Stuart, Ph.D./LESC
Terry F. Fleming/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 14 **Evaluation of the Orbital Replaceable Unit Alignment Target System**
Funded by: SSF
Technical Monitor: A. Jay Legendre/SP34
Principal Investigator(s): Carlos E. Sampaio/LESC
Ellen Hwang Snook/LESC
Terry F. Fleming/LESC
Mark A. Stuart, Ph.D./LESC
Task Performed by: Johnson Space Center
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HST 15 **Camera Placement Effects on Remote Manipulator Performance Using Rate and Position Control Modes**
Funded by: STS
Technical Monitor: A. Jay Legendre/SP34
Principal Investigator(s): Meera K. Manahan/LESC
Ellen Hwang/LESC
John M. Bierschwale/LESC
Mark A. Stuart, Ph.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 16 **Preliminary Evaluation of Partially Constrained Motion Using 2-by-3 Degree-of-Freedom Hand Controllers**
Funded by: SSF
Technical Monitor: A. Jay Legendre/SP34
Principal Investigator(s): Terry F. Fleming/LESC
Carlos E. Sampaio/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 17 **Evaluation of Prototype Force-Torque Displays**
Funded by: SSF
Technical Monitor: A. Jay Legendre/SP34
Principal Investigator(s): Robert C. Hendrich/LESC
John M. Bierschwale/LESC
Mark A. Stuart, Ph.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 18 **Astronaut Science Advisor Human-Computer Interface**
Funded by: RTOP 506-71
Technical Monitor: Marianne Rudisill, Ph.D./SP34
Principal Investigator(s): Jurine A. Adolf/LESC
Kritina L. Holden, Ph.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 19 **Extravehicular Activity Electronic Cuff Checklist Prototype**

Funded by: RTOP 506-71
Technical Monitor: Marianne Rudisill, Ph.D./SP34
Principal Investigator(s): Jurine A. Adolf/LESC
Kritina L. Holden, Ph.D./LESC
Michael R. O'Neal/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 20 **Human-Computer Interface to Medical Decision Support Systems for Space**

Funded by: RTOP 199-06
Technical Monitor: Marianne Rudisill, Ph.D./SP34
Principal Investigator(s): Jurine A. Adolf/LESC
John Gosbee, M.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 21 **Human-Computer Interfaces to Intelligent Systems**

Funded by: RTOP 506-71
Principal Investigator(s): MarianneRudisill, Ph.D./SP34
Evan Feldman/LESC
Kevin O'Brien, Ph.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 22 **Display Screen Coding with Color**

Funded by: RTOP 506-71
Technical Monitor: Marianne Rudisill, Ph.D./SP34
Principal Investigator(s): Kevin O'Brien, Ph.D./LESC
Kim Donner/Rice University
Timothy McKay, Ph.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 23 **Human-Computer Interface to Geographical Information Systems for Space**

Funded by: RTOP, OAET SEI
Technical Monitor: Marianne Rudisill, Ph.D./SP34
Principal Investigator(s): Kevin O'Brien, Ph.D./LESC
Benjamin Beberness/LESC
Steven Chrisnan/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 24 **Space Station Freedom Flight Human-Computer Interface Standards: SSP 30570**

Funded by: SSF
Principal Investigator(s): Marianne Rudisill, Ph.D./SP34
Kritina L. Holden, Ph.D./LESC
Jurine A. Adolf/LESC
Benjamin Beberness/LESC
J. M. Loman/MDSSC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.
McDonnell Douglas Space Systems Co.

HST 25 **Human-Computer Interface to Electronic Procedures Research**

Funded by: RTOP 506-71
Principal Investigator(s): Marianne Rudisill, Ph.D./SP34
Michael R. O'Neal/LESC
Timothy McKay, Ph.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 26 **Human-Computer Interface to Multitasking**

Funded by: RTOP 506-49
Principal Investigator(s): Marianne Rudisill, Ph.D./SP34
Steve Chrisman/LESC
Kritina L. Holden, Ph.D./LESC
Michael R. O'Neal/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 27 **Designing a Cursor Control Device for Space Station Freedom**

Funded by: SSF
Principal Investigator(s): Dean Jensen, Ph.D./SP34
Marianne Rudisill, Ph.D./SP34
Robert P. Wilmington/LESC
Kritina L. Holden, Ph.D./LESC
Mihriban Whitmore, Ph.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 28 **Tools and Methods for User-Intelligent System Interaction Design**

Funded by: RTOP 506-71
Principal Investigator: Jane T. Malin, Ph.D./ER22
Task Performed by: Johnson Space Center
Mitre Corporation

HST 29 **Human Factors Assessment of Spacelab Missions**

Funded by: RTOP 199-08
Principal Investigator(s): Susan Adam/SP34
John Gosbee, M.D./LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 30 **Task Network Models of Performance in Microgravity**

Funded by: RTOP 199-06
Principal Investigator(s): Susan Adam/SP34
Manuel Diaz/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 31 **Partial Gravity Simulation Development**

Funded by: SEI 326-84
Principal Investigator(s): David Ray/SP52
Vernon Granger/JEC
Gordon Miller/JEC
Brian Petty/JEC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

HST 32: **C Language Integrated Production System**

Funded by: Civil Service
Principal Investigator(s): Gary Riley/PT4
Chris Culbert/PT4
Brian Donnell/PT4
Robert T. Savely/PT4
Performed by: Johnson Space Center

HST 33: **Advanced Software Development Workstation**

Funded by: Codes MD, MT
Principal Investigator: Ernest M. Fridge III/PT4
Charles L. Pitman/PT4
Performed by: Johnson Space Center
Knowledge Based Systems Inc.
Inference Corp.

HST 34: **Intelligent Tutoring Systems Integrated with Simulators**

Funded by: SBIR (Code CR)
Principal Investigator(s): Thomas T. Chen/GIS
Diann E. Barbee/ GIS
Robert T. Savely/PT4
Performed by: Global Information Systems (GIS)
Johnson Space Center

HST 35: **The Intelligent Physics Tutor**

Funded by: OSF
Principal Investigator(s): Robert T. Savely/PT4
Dr. R. Bowen Loftin/U. Houston-Downtown
Performed by: Johnson Space Center
University of Houston-Downtown

HST 36: **Intelligent Computer-Aided Training**

Funded by: Codes MD and MT
Principal Investigator(s): Robert T. Savely/PT4
Dr. R. Bowen Loftin/U. Houston-Downtown
Performed by: Johnson Space Center
University of Houston-Downtown

HST 37: **Passive Knowledge Acquisition System**

Funded by: SBIR (CR)
Principal Investigator(s): Vince Kovarik/Software Productivity Solutions, Inc.
Robert T. Savely/PT4
Performed by: Software Productivity Solutions, Inc.
Johnson Space Center

HST 38: **SimTool: An Integrated Environment for Simulation Construction, Operation, and Maintenance**

Funded by: SBIR
Principal Investigator(s): Ernest M. Fridge III/PT4
Randall D. Barnette/LinCom Corporation
Performed by: Johnson Space Center
LinCom Corporation

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HST 39: **NASA Electronic Library System**

Funded by: Institutional Funding
Principal Investigator(s): Ernest M. Fridge III/PT4
Mark Rorvig/PT4
Performed at: Johnson Space Center
Barrios Technology, Inc.

HST 40: **Software Development Cost Estimation Model for Space Station Freedom**

Funded by: Civil Service
Principal Investigator(s): Bernie Roush/PT4
Bill Reini/PT4
Performed by: Johnson Space Center

HST 41: **NETS: A Tool for the Development and Delivery of Neural Networks**

Funding source: Civil Service
Principal Investigator: R. Shelton/PT4
Performed by: Johnson Space Center

HST 42: **Parametric Avalanche**

Funded by: SBIR
Principal Investigator(s): R. Shelton/PT4
R. Dawes/Martingale
Performed by: Johnson Space Center
Martingale Research Corporation

HST 43: **Adaptive Control of a Robot Arm Using an Artificial Neural Net with Stereo Vision Input**

Funded by: Center Director's Discretionary Fund
Principal Investigator: Timothy F. Cleghorn, Ph.D./PT41
Performed by: Johnson Space Center
Symbus Technologies Inc.

HST 44: **Fuzzy Cognitive Maps for Mission Planning and Flight Control**

Funded by: SBIR
Principal Investigator(s): Robert N. Lea/PT4
Dennis Toms/TACAN Corp.
Performed by: Johnson Space Center
TACAN Corp.

HST 45: **Fuzzy-CLIPS: The C Language Integrated Production System with Fuzzy Logic Capability**

Funded by: SBIR
Principal Investigator(s): Robert N. Lea/PT4
Yashvant Jani/Togai Infralogic
Jack Aldridge/Togai Infralogic
Performed by: Johnson Space Center
Togai Infralogic

HST 46: **Fuzzy Logic for Adaptive Control and Operational Decision Making**

Funded by: OSF/Code MD
Principal Investigator: Robert N. Lea/PT4
Performed by: Johnson Space Center
LinCom Corp
Togai Infralogic

HST 47	**Knowledge-Based System Verification and Validation**	
	Funded by:	Institutional Funding
	Principal Investigator:	Chris Culbert/PT4
	Task Performed by:	Johnson Space Center IBM
HST 48	**Cooperating Expert Systems**	
	Funded by:	Code MD and Code MT
	Principal Investigator:	Chris Culbert/PT4
	Task Performed by:	Johnson Space Center McDonnell Douglas

Reference Number	SOLAR SYSTEM SCIENCES (SSS)	
SSS 1	**Water-Based Chemistry in Martian Meteorites**	
	Funded by:	RTOP 152-11-40-22
	Principal Investigator:	James L. Gooding, Ph.D./SN21
	Task Performed by:	Johnson Space Center
		Lockheed Engineering & Sciences Co. (LESC), NAS9-17900
SSS 2	**Martian Water: First Direct Analysis in a Terrestrial Laboratory?**	
	Funded by:	199-52-11-01
	Principal Investigator(s):	Everett K. Gibson, Ph.D./SN2
		Haraldur R. Karlsson, Ph.D./NRC
	Task Performed by:	Johnson Space Center
		National Research Council (NRC)
SSS 3	**Hypervelocity Penetrations of Dimensionally Scaled Targets**	
	Funded by:	152-88-40-22
	Principal Investigator:	Friedrich Hörz, Ph.D./SN2
	Task Performed by:	Johnson Space Center
SSS 4	**Debris Concerns in Geosynchronous Orbit: Perturbations and Stable Planes**	
	Funded by:	906-34-01-01
	Principal Investigator:	Donald J. Kessler, Ph.D./SN3
		Herbert A. Zook/SN3
		Larry J. Friesen, Ph.D./LESC
	Task Performed by:	Johnson Space Center
		Lockheed Engineering & Sciences Co. (LESC), NAS9-17900
SSS 5	**Pneumatic Conveying of Solids in Partial Gravity**	
	Funded by:	Code R/593-82-11-02
	Principal Investigator:	Thomas A. Sullivan, Ph.D./SN14
	Task Performed by:	Johnson Space Center
SSS 6	**Space Radiation Measurement, Analysis, and Predictions**	
	Funded by:	Code M/568-12-KF-01
		Code R/472-21
	Principal Investigator(s):	Gautam D. Badhwar, Ph.D./SN3
		Michael J. Golightly/SN3
		Alva C. Hardy/SN3
		James E. Keith, Ph.D./SN3
		Andrei Konradi, Ph.D./SN3
	Task Performed by:	Johnson Space Center

Reference Number

SPACE SYSTEMS TECHNOLOGY (SST)

SST 1 **EOIM-3 Atomic Oxygen Effects Experiment**
Funded by: 506-43
Principal Investigator(s): James T. Visentine/ES
Steven L. Koontz, Ph.D./ES
Task Performed by: Johnson Space Center

SST 2 **Experimental Investigations of Spacecraft Glow**
Funded by: 589-01
Principal Investigator: James T. Visentine/ES
Task Performed by: Johnson Space Center
Lockheed-Palo Alto Research Laboratory

SST 3 **Production of Construction Bricks from Lunar Soil**
Funded by: 506-43
Principal Investigator(s): David Altemir/ES
Joy Hines/ES
Task Performed by: Johnson Space Center

SST 4 **Regenerative Life Support Systems Test-Bed Crop Tests**
Funded by: 307-51
Principal Investigator(s): Donald L. Henninger/EC3
Terry O. Tri/EC3
Daniel J. Barta/EC3
Randal S. Stahl/EC3
Marybeth A. Edeen/EC7
Task Performed by: Johnson Space Center

SST 5 **Silver Oxide Carbon Dioxide Removal**
Funded by: 472-45
Principal Investigator: Robert J. Cusick/EC3
Task Performed by: Johnson Space Center
Hamilton Standard

SST 6 **Fundamental Process Enhancements in Electrochemical Carbon Dioxide Removal**
Funded by: 506-41
Principal Investigator: Sandra L. Foerg/EC3
Task Performed by: Johnson Space Center

SST 7 **Failure Tolerance in Manipulator Design for Space Operations**
Funded by: 595-11
Principal Investigator: John T. Chiadek/ER43
Task Performed by: Johnson Space Center

SST 8 **Failure-Tolerant Manipulator Joint and Controller Development**
Funded by: 590-11
Principal Investigator: John T. Chiadek/ER43
Task Performed by: Johnson Space Center

SST 9 **Laser Orientation Transceiver System**
Funded by: 324-01
Principal Investigator: J. L. Prather/EE
Task Performed by: Johnson Space Center

SST 10 **Wireless Infrared Data Acquisition System**

Funded by: 141-20
Principal Investigator: K. F. Dekome/EE
Task Performed by: Johnson Space Center
Wilton Industries

SST 11 **Image-Based Tracking System**

Funded by: 906-30
Principal Investigator: T. E. Fisher/EE
Task Performed by: Johnson Space Center

SST 12 **Optical Communication Through the Shuttle Window**

Funded by: 906-30
Principal Investigator: J. L. Prather/EE
Task Performed by: Johnson Space Center

SST 13 **Laboratory Demonstration of Innovative, Compact, 3-Dimensional Imaging Sensor**

Funded by: 324-01
Principal Investigator: K. F. Dekome/EE
Task Performed by: Johnson Space Center

SST 14 **Exponential Grids in Robotic Vision**

Funded by: 324-02
Principal Investigator: R. D. Juday/EE
Task Performed by: Johnson Space Center

SST 15 **Hierarchical 3-Dimensional and Doppler Imaging Laser Radar**

Funded by: 324-02
Principal Investigator: J. L. Prather/EE
Task Performed by: Johnson Space Center

SST 16 **Optical Correlation**

Funded by: 951-15
Principal Investigator: R. D. Juday/EE
Task Performed by: Johnson Space Center

SST 17 **Autonomous Guidance**

Funded by: 906-21
Principal Investigator: Gene McSwain/EG221
Task Performed by: Johnson Space Center

SST 18 **Control Technogy**

Funded by: 506-59
Principal Investigator: John Sunkel/EG1
Task Performed by: Johnson Space Center

SST 19 **Advanced Flight Data System Architectures**

Funded by: 906-11
Principal Investigator: David Pruett/EK11
Task Performed by: Johnson Space Center
Boeing
Lockheed Engineering & Sciences Co.

SST 20 **Full Color Flat Panel Display**

Funded by: 324-02
Principal Investigator: Andrew Farkas/EK6
Task Performed by: Johnson Space Center

SST 21 **Space Station Heat Pipe Advanced Radiator Element II**

Funded by: 472-45
Principal Investigator: Steven D. Glenn/EC2
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

SST 22 **Investigation of Long-Term Stability in Metal Hydrides**

Funded by: 506-41
Principal Investigator: Patricia A. Petete/EC2
Task Performed by: Johnson Space Center
Hydrogen Consultants, Inc.

SST 23 **Making Intelligent Systems Team Players: Design for Human Interaction**

Funded by: 590-12
Principal Investigator: J. T. Malin/ER22
Task Performed by: Johnson Space Center
MITRE

Reference Number

SPACE TRANSPORTATION TECHNOLOGY (STT)

STT 1 **Rendezvous Expert System**
Funded by: 906-21
Principal Investigator: H. K. Hiers/ER2
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

STT 2 **CONFIG Intelligent Modeling and Analysis Automation**
Funded by: 951-15
Principal Investigator: J. T. Malin/ER22
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.
MITRE

STT 3 **Mission Evaluation Room Intelligent Diagnostic and Analysis System**
Funded by: 551-12
Principal Investigator: G. L. Pack/ER221
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

STT 4 **Telepresence Workstation Development**
Funded by: 992-15
Principal Investigator: Michael J. Stagnaro/ER43
Task Performed by: Johnson Space Center

STT 5 **Advanced Avionics Architecture (Development Pathways)**
Funded by: 906-11
Principal Investigator: Don C. Brown/EG1
Task Performed by: Johnson Space Center

STT 6 **Autonomous Rendezvous and Docking Ground Demonstration**
Funded by: 593-14
Principal Investigator: Steve Lamkin/EG431
Task Performed by: Johnson Space Center

STT 7 **Rendezvous, Proximity Operations, and Capture Quality Function Deployment**
Funded by: 593-14
Principal Investigator: Steve Lamkin/EG431
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.
TRW
Charles Stark Draper Laboratories
McDonnell Douglas Space Systems Co.-Houston
Martin Marietta
General Dynamics

STT 8 **Extravehicular Maneuvering Unit Electronic Cuff Checklist**
Funded by: 506-71
Principal Investigator: Jose Marmolejo/EC6
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co.

STT 9 **Shuttle Remote Manipulator System Advanced Force/Torque Control**

Funded by: 590-11
Principal Investigator: Donald A. Barron/ER3
Task Performed by: Johnson Space Center

STT 10 **Rocket Research Long-Life Hydrazine Thruster Progam**

Funded by: 472-
Principal Investigator: Christopher G. Popp/EP4
Task Performed by: Johnson Space Center
Rocket Research Company

STT 11 **Primary Reaction Control System Thruster Metallic Nitrate Flushing**

Funded by: 551-
Principal Investigator: John Albright/EP4
Task Performed by: Johnson Space Center
White Sands Test Facility

STT 12 **Rocket Engine Combustion Stability**

Funded by: 551-
Principal Investigator(s): Eric Hurlbert/EP4
Howard Flynn/EP4
Task Performed by: Johnson Space Center
McDonnell Douglas Space Systems Co.

STT 13 **Aeroassist Flight Experiment**

Funded by: 592-01
Principal Investigator(s): Donald Curry/ES
Vuong Pham/ES
Carlos Ortiz/ES
Christopher Madden/ES
James Milhoan/ES
Robert Maraia/ES
Task Performed by: Johnson Space Center
Marshall Space Flight Center

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16. Abstract

The Johnson Space Center (JSC) Research and Technology (R&T) Report presents the accomplishments of the Center during Fiscal Year 1991. The report serves to communicate within and outside the Agency significant R&T JSC activities and identifies principal researchers and technologists as contacts for further information. This report is organized into five sections: Life Sciences, Human Support Technology, Solar System Sciences, Space Systems Technology, and Space Transportation Technology. Each of these sections is comprised of a summary followed by detailed descriptions of significant tasks. The task descriptions are written, not with technical jargon, but in a style that aids comprehension with the use of data and illustrations. Special attention is paid to define acronyms and special technical terms. The report can therefore be used by both technical management communities. A listing of project descriptions, along with funding code and principal investigators, is provided in the Index of this report.

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